BSc Creative Technology

Design of Urban Parks Using Wave Function Collapse

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Abstract

Urban parks play a crucial role in enhancing the quality of life in cities by providing recreational spaces, promoting social interaction, and contributing to environmental sustainability. In addition to that, many stakeholders are involved that want to express their needs. This results in a complex design process. This thesis explores the application of Procedural Content Generation (PCG) techniques, specifically the Wave Function Collapse (WFC) algorithm, to inform and innovate the urban park design process.

The study begins with a comprehensive review of the literature on the purpose and design principles of urban parks, followed by an examination of various PCG methods suitable for urban design. Among these, the WFC algorithm is selected for its ability to generate diverse and coherent spatial patterns based on a set of input constraints. The primary objective of this research is to evaluate the feasibility and effectiveness of using WFC for urban park design.

To gather expert insights, an interview was conducted with a landscape architect. The findings highlight key values and requirements that must be addressed in the design process, such as accessibility, biodiversity, and aesthetic appeal. These insights inform the development of design requirements and guide the implementation of the WFC algorithm.

The methodology section details the selection and application of the WFC algorithm. Key concepts such as tile-based modeling, overlapping tiles, and tile rotation are explained. The implementation process involves creating custom tiles and experimenting with various design elements to achieve the desired park layout. The final prototype is evaluated against the predefined requirements through expert user tests and surveys.

The results indicate that the WFC algorithm is capable of generating functional and visually appealing urban park designs. The expert user test provided valuable feedback on the usability and practicality of the generated designs. The survey responses suggest that the approach has potential but requires further refinement to fully meet all stakeholder needs.

In conclusion, this thesis demonstrates the potential of integrating procedural content generation techniques, particularly the WFC algorithm, into the urban park design process. Although the initial results are promising, further research and development is necessary to optimize the algorithm and address any limitations. This study contributes to the growing field of computational urban design and opens new avenues for innovative and efficient park planning.

Acknowledgment

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Acronyms

PCG Procedural Content Generation

GIS Geographic Information System

WFC Wave Function Collapse

MJ Markov Junior

MS Modeling Synthesis

AI Artificial Intelligence

Chapter 1

Introduction

Urban parks play a vital role in the development of cities; they can enhance the quality of urban environments and provide various health, economic, and social benefits [5]. In addition, they can improve the quality of life, sustainability and public health of a city [1]. During the design process, there are many different stakeholders involved. Taking into account the diverse interests and requirements of these stakeholders, the design of an urban park is a complex process. This paper explores how a constraint-based Procedural Content Generation (PCG) algorithm could be useful in the urban park design process. "PCG is the algorithmic creation of game content with limited or indirect user input" [6]. This research explores the potential of its application outside of the creation of game content. These algorithms can efficiently manage complex design requirements, by generating viable layouts quickly and consistently while adhering to predefined design rules and constraints. According to Roumpani [7], PCG tools can potentially help evaluate the early designs of urban parks.

This research investigates how a constraint-based PCG algorithm can be applied to the design of urban parks. Therefore, the main goal is to create a tool with an implementation of such an algorithm that would help the urban park design process. To be more specific, this paper will attempt to answer the following research question.

> **MQ**: How can a constraint-based procedural content generation algorithm inform the design of urban parks?

To answer this question multiple algorithms need to be examined. To develop the tool constraints need to be determine. So for this research to go more in depth there are these sub questions:

> **SQ**: At what stage can a constraint-based procedural content generation algorithm inform the design of urban parks?

> **SQ**: What constraints must be considered when applying a constraint-based procedural content generation algorithm to urban park design?

This research report aims to provide a thorough overview of the design and development process of the tool and is therefore structured into several chapters.

- **Chapter 2: Background Research** - This chapter discusses existing projects that utilize procedural modeling for urban park design, providing a theoretical foundation for the research.
- **Chapter 3: Expert Insight** - Presents a stakeholder analysis, insight from an expert on the design process of urban parks and discusses important values for urban park design.
- **Chapter 4: Methods and Techniques** - Outlines the methodology and techniques employed in this research, detailing the processes of algorithm selection, research, implementation, and design.
- **Chapter 5: Implementation** - Presents the implementation, including a detailed description of the prototype and its assessment in relation to the initial requirements.

- **Chapter 6: Evaluation** - Outlines the results from a expert user test and a survey to evaluate the tool.
- **Chapter 7: Discussion** - Discusses the findings of the research, explores the implications, and suggests areas for future work.
- **Chapter 8: Conclusion** - Summarizes the research, highlighting the main contributions and the impact on urban park design.

Chapter 2

Background Research

Before applying an algorithm to the urban park design process, it is important to better understand how these algorithms can be implemented and how they could aid the design of urban parks. Therefore, the main goal of this section is to provide an overview of existing procedural modeling algorithms that can be applied to the design of urban parks. Firstly, this background research will focus on how urban parks are designed, secondly, explore existing procedural urban modeling tools, and finally describe potential algorithms that could be of aid in designing urban parks.

2.1 Purpose of Urban Parks

Urban parks play a vital role in improving community health and supporting environmental sustainability. These green spaces are essential in cities, encouraging social interactions, promoting well-being, and providing numerous ecological benefits. They serve as communal areas where people of all ages can gather, participate in recreational activities and connect with nature, contributing to a stronger sense of community and an improved quality of life.

According to Kolimenakis et al. [8], urban parks offer cultural and educational advantages and improve physical and mental health. They serve as venues for cultural events, educational programs, and public art installations, enriching the cultural fabric of the city. In addition, urban parks help regenerate clean air, soil and water and provide protection against natural disasters by acting as natural buffers. The presence of green spaces in urban areas also helps reduce the effect of heat islands in urban areas, leading to cooler and more comfortable city environments.

Rigolon [9] states that urban parks improve public health by offering spaces for physical activities and connecting people with nature. These areas provide opportunities for exercise, relaxation, and escape from urban stress, which are crucial to mental health. The accessibility of green spaces encourages physical activity, such as walking, jogging, and cycling, which can help reduce the prevalence of lifestyle-related diseases. In addition, urban parks contribute to environmental sustainability through ecosystem services, such as capturing carbon dioxide, preserving biodiversity, and regulating temperature. They also offer venues for community gatherings and recreational activities, fostering social cohesion and inclusivity.

In general, urban parks are invaluable assets for cities. They improve residents' quality of life by positively impacting well-being and the environment. Their multifaceted benefits highlight the importance of incorporating and maintaining green spaces in urban planning and development. By integrating urban parks into the urban landscape, cities can create healthier, more sustainable and more vibrant communities that cater to the diverse needs of their residents.

2.2 Design of Urban Parks

This section explores the evolution of urban park design, emphasizing the move from focusing primarily on physical features to including broader social interactions and user experiences. Finally, the use of software in urban park design is discussed.

Over the years, the evaluations of urban park quality have changed. Chen et al. [5] suggest that traditionally, research on urban parks has focused on physical and spatial aspects, such as the availability, accessibility, and proximity of parks, which are determined by their number and size, and how close they are to other neighborhood amenities. Yet, to truly capture the essence of what urban parks offer, it is imperative to also consider non-spatial dimensions. These include aspects that directly impact human experiences and behaviors in park settings, going beyond the mere physical attributes of the parks. In addition to that, in a later study Chen et al. [10] state that after the coronavirus pandemic social interactions are also important, creating more inclusive and engaging urban spaces. The focus of urban park evaluation has changed from physical and structural attributes to incorporating user perceptions and interactions.

Considering that the research on the evaluation of urban parks has changed, it is important to follow design principles to improve the qualities of the park. According to Chen et al. [5], both spatial and non-spatial assessments are deemed critical in the design of urban parks. In a later study, Chen et al. [10] provide a design guideline for park quality to also promote social interaction in urban parks. They highlight that overall park quality, such as facility, amenity, aesthetic features, maintenance & cleanliness, and incivility are most significant. On the other hand, Halecki et al. [1] focus more on the aspect of climate change. They suggest that green wedges play a vital role around urban buildings as part of a strategy to improve biodiversity, improve the quality of life of residents, and address climate change challenges. The structure of these wedges is shown in Figure 2.1. The overall quality of the park will improve by focusing on physical characteristics, promoting social interactions, and environmental sustainability.

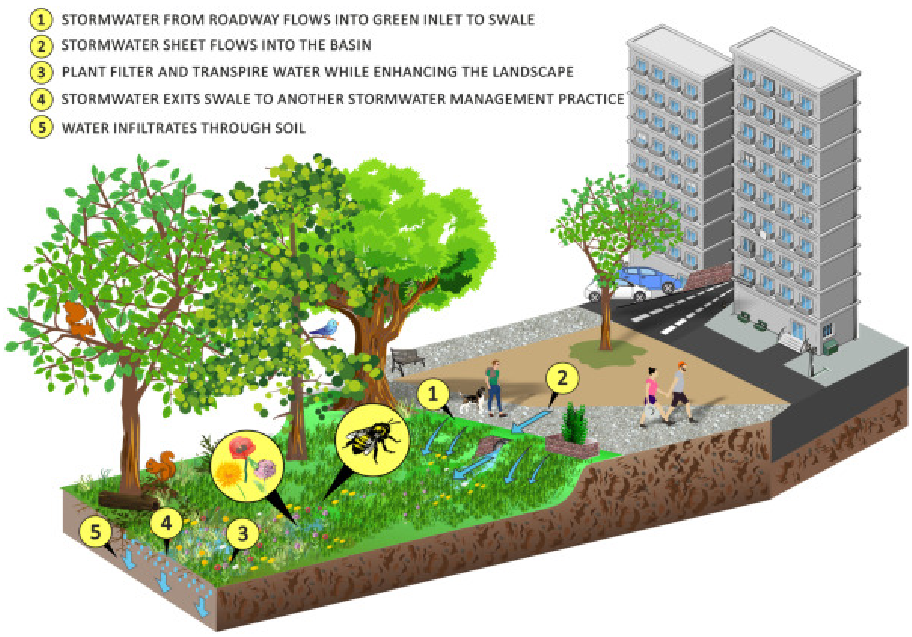


Figure 2.1: The role of green wedges in the inner-city [1].

Geographic Information Systems are computer-based tools that are used to store, visualize, analyze and interpret geographic data that could potentially be useful for urban park design. Halecki et al. [1] propose that advancement in technology, particularly the increase in computing technology and the use of Geographic Information System (GIS) tools, improves the creation of urban parks. Essential to this process is the availability of data on the allowed or potential development of green spaces and the enhancement of the functionality of buildings and broader regions in response to climate change. Chen et al. [5] briefly discuss the use of GIS in combination with other tools to evaluate parks. They note that GIS can provide valuable spatial data, but it should be integrated with other data collection methods to capture a better view of park use. That does not exclude that it could be useful for the process of designing urban parks. This discussion highlights the evolving role of GIS in urban park design, where it is seen as a vital tool for spatial planning and data analysis, but also a tool that should be part of a broader toolkit to ensure comprehensive park evaluation and effective design.

In general, urban parks improve overall health, support environmental sustainability, and improve social cohesion in cities. Over time, the focus of urban park evaluation has shifted from just physical attributes to include user experiences and social interactions. With that, it is important to consider both spatial and non-spatial assessments. GIS could also be a valuable tool during the design process and could be used even more broadly when integrated with other data collection methods.

2.3 Procedural Modeling in Urban Design

This section explores the value of procedural urban modeling to support the early stages of urban design. The paper discusses existing tools, such as CityEngine, and the challenges associated with them. In addition, it examines other implementations, such as vegetation mapping and road network generation.

Procedural modeling can be a useful tool to generate urban designs. According to Watson et al. [11] procedural modeling can simplify the production of visualizations of cities. These can be entire cities or specific parts of cities like buildings, roads, parks, etc. It is a versatile tool in diverse geographical contexts [12].These examples illustrate how procedural modeling can be a useful tool in urban design. For example, procedural modeling has been used effectively in simulating various urban scenarios, such as traffic flow and environmental impact assessments, which are crucial for informed decision making in urban planning. These examples illustrate how procedural modeling can be a helpful tool in urban design.

CityEngine is a good example of procedural urban design modeling. According to Watson et al. [11] and Badwi et al. [12] CityEngine is a powerful procedural urban modeling tool. It uses procedural modeling techniques to create the algorithms that are used to procedurally model a city. In addition, they have many working integrations with other programs, as shown in Figure 2.2. Based on the results of their research, Badwi et al. [12] confirm the effectiveness of CityEngine as a well-working 3D modeling program in urban planning processes. However, they also note some limitations, as it is not possible to use curved shapes and polygons. Despite these limitations, CityEngine demonstrates the potential of procedural modeling techniques to generate complex urban designs.

(a) A park generated in CityEngine.

(b) The same park exported to Unreal Engine and all assets replaced with high-quality Unreal versions.

Figure 2.2: A park generated by CityEngine brought to life in Unreal Engine.

In addition to CityEngine, there are other existing procedural models for creating virtual urban designs. Niese et al. [13] developed procedural placement models for vegetation in urban areas. They translate satellite images into vegetation coverage maps to determine the distribution of vegetation within a city, allowing them to reconstruct similar vegetation patterns. In figure 2.3, you can see an example of Central Park, New York. Nishida et al. [14] present another system to create urban road networks, which is also built upon procedural modeling. These tools illustrate the diverse applications of procedural modeling in urban design, from vegetation placement to road network generation.

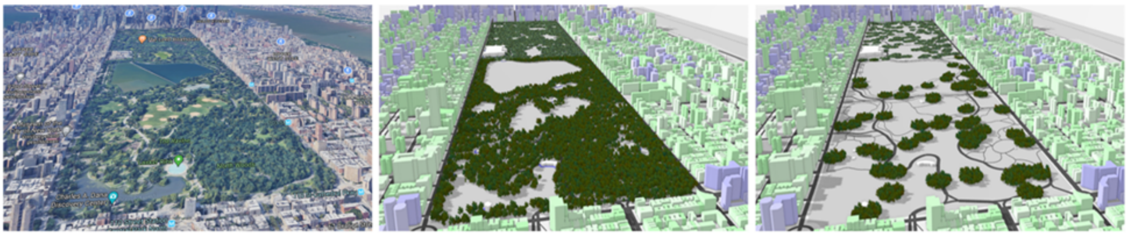


Figure 2.3: Left: Google Maps view of New York (Central Park). An example of a procedural vegetation tool that generated to variants of plant placements (middle, right) for an initially empty city model

Procedural modeling comes with its challenges and limitations. Badwi et al. [12] conclude that when it comes to CityEngine, the interface makes it challenging to use in the urban design process. Watson et al. [11] suggest that further development in procedural detail and control will help realize the full potential of procedural urban modeling. Furthermore, procedural modeling requires specialized knowledge to create the parameter values used in designs [14]. This creates a skill gap, as these tools are not yet user-friendly for all urban designers. Therefore, there is still significant room for improvement in making these tools more accessible and intuitive.

Procedural urban modeling tools, such as CityEngine, play a significant role in supporting early-stage urban design by providing visualizations and simulations of various urban elements. Studies, including those by Watson et al. [11] and Badwi et al. [12], show the versatility and effectiveness of these tools in applications such as vegetation mapping and road network generation. However, challenges remain, particularly with respect to user-friendliness and handling complex geometric shapes. Research indicates that further development is needed to address these issues and make procedural modeling more accessible to urban designers. As technology evolves, it has the potential to become an even more integral part of urban planning processes.

2.4 Potential PCG Methods for Urban Park Design

This section explores several PCG methods that could be particularly useful for the design of urban parks. These methods offer various ways to create detailed, dynamic, and scalable urban environments, leveraging both traditional procedural techniques and modern advances in artificial intelligence and machine learning.

2.4.1 Model Synthesis

Modeling Synthesis (MS) is a PCG algorithm used to create large-scale models based on example-based synthesis techniques. It generalizes texture synthesis algorithms to produce extensive, coherent models. Merrell and Manoch [15] introduced MS as a means to automate the creation of complex environments. According to Niese et al. [13], MS enables the purely procedural modeling of infinite cities, making it a powerful tool for urban park design. Its simplicity in implementation and flexibility in handling various input data make it an attractive option for urban planners seeking to generate vast and detailed urban landscapes.

2.4.2 Wave Function Collapse

WFC is an algorithm inspired by the principles of quantum mechanics, applied to the generation of procedural content. Developed by Maxim Gumin [16], WFC generates new models based on adjacency constraints between tiles in a sample model. Unlike traditional tiling algorithms, WFC works with overlapping patterns, providing greater control over the similarity between the output and the input model. By adjusting the overlap amount, designers can fine-tune the generated urban parks to closely mimic desired layouts. This flexibility makes WFC suitable for creating intricate and aesthetically pleasing urban environments.

2.4.3 Markov Junior

Markov Junior (MJ) is a probabilistic programming language derived from Markov algorithms, which use a series of rewrite rules applied to a grid-based system. As described by Gumin [17], MJ is capable of creating complex and dynamic models, such as mazes, urban roads and forest within urban settings. The algorithm's sequential application of rewrite rules allows for significant creativity and flexibility, translating high-level design rules into detailed procedural outputs. This makes MJ a valuable tool for urban park design, where diverse and adaptive landscapes are essential.

2.4.4 AI and Machine Learning

Artificial Intelligence (AI) and machine learning algorithms have transformed the field of PCG by leveraging large datasets to identify patterns and generate optimized urban designs. Techniques such as neural networks and decision trees can analyze factors such as population density, traffic flow, and environmental impact to optimize the placement of urban characteristics. These methods can improve the design of urban parks by ensuring that they meet the needs of the community and adhere to environmental standards. Studies show that AI-driven design processes can significantly enhance both the efficiency and quality of urban planning [12].

2.4.5 Generative AI

Generative AI, including large language models, represents the frontier of procedural modeling. These models learn from vast amounts of urban design data to generate new design proposals, simulate urban growth scenarios, and offer optimization suggestions for existing layouts. Generative AI can create highly detailed and innovative urban park designs, as it can incorporate a wide range of variables and constraints in its models. Research indicates that Generative AI can substantially increase the creativity and effectiveness of the urban design process, making it a promising tool for the future of urban planning [11].

The exploration of various PCG algorithms highlights their potential in enhancing urban park design. From traditional methods like MS and WFC to advanced techniques involving AI and Generative AI, these tools offer diverse approaches to creating detailed, dynamic, and scalable urban environments. While each algorithm has its strengths and limitations, their combined application can address the complex requirements of modern urban planning. Continued research and development in these areas will further improve their usability and effectiveness, ultimately contributing to more efficient and innovative urban design processes.

2.5 Summary

Urban parks have an overall positive effect on cities. Not only physical attributes are important, but also user experiences and social interactions. That means that when using a PCG algorithm it is important to consider both spatial and non-spatial aspects. GIS tools play an important role in the development of a park. A GIS integrated with an algorithm could be very valuable. An existing procedural modeling tool, CityEngine, already uses a GISs. This makes it a versatile tool that allows designers to visualize their ideas in a great deal of detail. The downside of this program is that it can be very complex, especially for new users. A key point that could be used for further research is looking into how to make such an algorithm more user-friendly. Because eventually procedural modeling plays an evolving role in urban planning and is continuously adapting. This chapter examined five different PCG methods that could potentially be very useful for urban design.

Chapter 3

Expert Insight

This chapter discusses the process of conducting an expert interview, outlines the results obtained, and extracts key insights from these findings for the remainder of the research.

3.1 Conducting the Expert Interview

To gain insight into the urban park design process, an in-depth interview was conducted with a landscape architect who works for the municipality of Enschede. This interview aimed to explore the multifaceted roles and responsibilities involved in landscape architecture, especially focusing on the design and development of urban parks. The interview process was properly planned and executed, ensuring a complete understanding of the subject matter.

3.1.1 Interview Preparation

The first step involved identifying and selecting an appropriate expert who had extensive experience in landscape architecture and urban park design. The selected expert was a landscape architect with a significant portfolio of urban park projects, ensuring that the information collected was relevant and insightful. A detailed interview guide was developed to structure the conversation and ensure that all relevant topics were covered. The guide included general questions about the expert's role and responsibilities, specific questions about the design process and tools used, and open-ended questions to allow for in-depth discussions. The guide was designed to obtain detailed responses that provided a holistic view of the field of landscape architecture. The complete interview guide is included in Appendix B. The interview was scheduled at a convenient time for the expert, ensuring that the conversation could proceed without interruptions. The interview was set to last approximately 30 minutes, allowing sufficient time to delve into both broad and specific aspects of urban park design.

3.1.2 Conducting the Interview

The interview began with a brief introduction, explaining the purpose of the graduation project, and describing the structure of the interview. This helped setting the context and making the interviewee comfortable. The first segment of the interview focused on general questions to gather background information on the expert's role and daily responsibilities. This segment provided a foundation for understanding the broader context in which the landscape architect operated. The interview then moved to more specific questions that were aimed at exploring the details of the design process. This included questions about the tools and methodologies used, the challenges faced, and the considerations taken into account when designing urban parks. This segment provided insights into the practical aspects of landscape architecture. An open discussion followed, allowing the expert to share additional insights, comments, or questions. This segment was crucial in uncovering any nuances or unique perspectives that might not have been addressed in the structured questions. The interview concluded with a summary of the key points discussed, thanks to the interviewee for their time and valuable contributions, and reiterating the importance of their insights for the research.

3.1.3 Data Analysis

During the interview, detailed notes were taken to capture the expert's responses accurately. This ensured that the information gathered was precise and allowed for a thorough analysis of the data. A thematic analysis was conducted to identify recurring themes and patterns within the interview data. The process involved coding the notes to categorize the information into various themes such as the design process, stakeholder analysis, important values, and current challenges in urban park design. The coded data were synthesized to extract meaningful insights and draw conclusions. This synthesis provided a comprehensive understanding of the landscape architectural field within urban settings, specifically highlighting the considerations and methodologies involved in designing urban parks.

3.1.4 Validation of Findings

The validated findings were then incorporated into the report, forming a crucial part of the results and contributing to the general understanding of the subject. The insights gained from the expert interview were particularly valuable in illustrating the practical aspects of urban park design and informing the development of the proposed computer tool to support designers in the early stages of the design process. Following this structured approach, the interview not only provided rich qualitative data, but also ensured that the findings were robust, reliable, and relevant to the objectives of the graduation project.

3.2 Results Expert interview

This subsection presents insights from an interview with a landscape architect, focusing on the urban park design process. In addition to developing a park aesthetically and ecologically, the architect's role also includes addressing the community needs and urban constraints. The interview offers an overview of the daily responsibilities, challenges faced, and methodologies used in the design process, providing a comprehensive understanding of the landscape architectural field within urban settings.

3.2.1 Design process urban parks

A landscape architect designs everything related to public spaces. Their specializations include extensive knowledge of the landscape and greenery. The designs they make are site-specific, as each part of the city is different. In addition, considerations such as climate change and social changes must be taken into account. Keeping these factors in mind, an architect tries to create the best possible design. These factors change continuously and are different for each location. As a designer, it is crucial to know where the clashes of various conditions lie and to find solutions for these. In the design process that a landscape architect uses, various competing demands need to be considered, which are illustrated by the example of a narrow street design. Designing a narrow street involves balancing multiple needs within limited space. The street must accommodate a certain number of parking spaces and greenery, along with necessary underground work for water storage. An example of such a street is given in Figure 3.1. Given the constraints, it is crucial to prioritize what is most important and make trade-offs. The process starts by identifying all the requirements. Choosing between more parking spaces and more greenery is a common decision. The goal is to make the design functional, attractive, and sustainable, ensuring that every decision is clear and justified to all parties involved.

The selection of materials for the street and the decision about the overall atmosphere are important. Considerations include which materials are best for durability and appearance, how to integrate greenery effectively, and how to manage water, whether stored above or below the ground. Starting with a basic cross section to understand space use helps in developing a practical and agreed-upon design. This methodical approach ensures that the final design meets both immediate needs and broader community goals. Tools such as SketchUp, AutoCAD, Adobe Illustrator, and Photoshop are used to visualize and

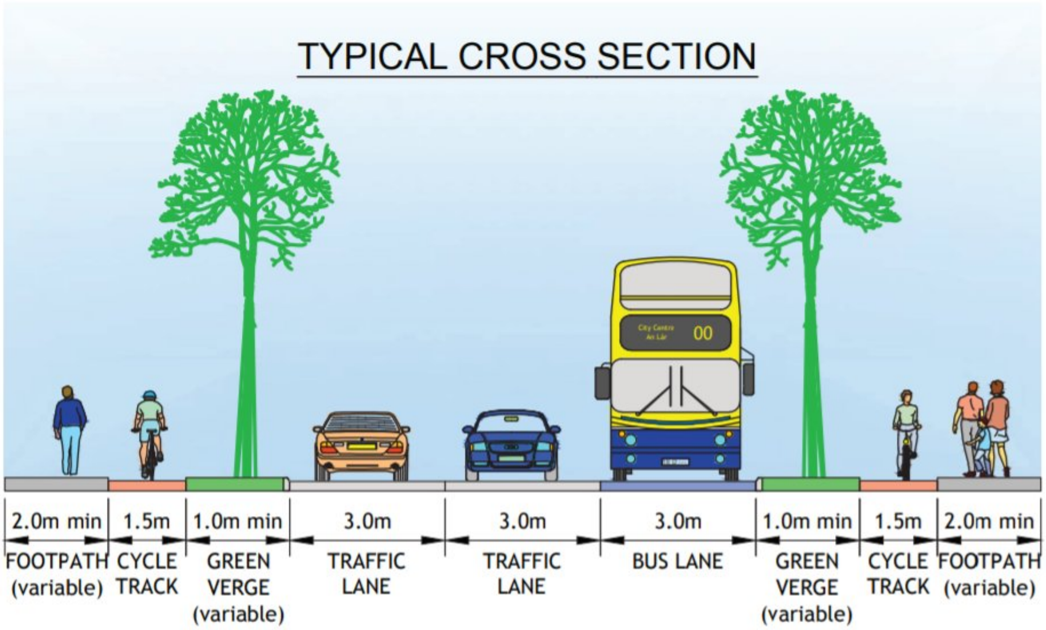


Figure 3.1: Cross-section of an urban street [2]

refine designs. These visual models help in discussing and adjusting the design based on how different elements fit together in the available space. The iterative process involves looking at the broader urban environment and then focusing on detailed design aspects. Multiple models with different priorities may be created if necessary, presenting these to stakeholders to gather feedback and preferences. The role of landscape architects is to coordinate the design process, continuously adapting and refining choices based on input.

3.2.2 Stakeholder Analysis

A diverse group of stakeholders is considered during the landscape architect's design process. These are the following:

- **Project Owner (Municipality):** In most urban development projects, the project owner is typically the municipality. This role involves initiating, funding, and overseeing projects, ensuring that they align with broader urban planning goals and regulations. The municipality is responsible for balancing the needs of the community with sustainable development practices to improve public spaces and infrastructure.
- **Team of Designers:**
  - **Urban Planners:** Their focus is on the integration of the park into the broader urban fabric, ensuring that the design aligns with city planning regulations and future urban development plans.
  - **Water Engineers:** Their role is to develop effective water management systems that can handle stormwater, ensuring that parks handle rain without flooding while keeping water features such as ponds and fountains running smoothly. Their work is crucial to keeping the park's environment healthy, appealing, and sustainable for the community.
  - **Traffic Engineers:** They are crucial in designing and managing the movement of vehicles, cyclists, and pedestrians around urban parks. They work on everything from improving road layouts and traffic flow to ensuring safe crosswalks and bike paths, designing parking facilities, and increasing public transit access. Their goal is to make parks easily accessible and safe without compromising the surrounding urban environment.

  - **Landscape Architect:** They design and enhance urban parks, balancing beauty and functionality. They collaborate with the various stakeholders to create sustainable, accessible environments that meet ecological and community needs, improving urban livability, and addressing environmental challenges.

- **Maintenance Workers:** They are responsible for the upkeep and care of park facilities, landscapes, and infrastructure. Their duties include landscaping, cleaning, repairing park structures, and ensuring that safety features are intact. They play a vital role in the preservation of the aesthetic appeal and usability of the park, helping to provide a clean, safe, and welcoming environment for the public.

- **City Residents:** They are members of the local community who use and benefit from urban spaces such as parks, roads, and public services. City residents are the primary users of the park. They are key stakeholders in urban development projects because their feedback and needs help shape the planning and maintenance of these spaces, ensuring the city remains livable and meets its daily needs.

Each group brings different expectations and requirements that must be balanced to create functional and sustainable urban green spaces. Active participation and feedback from these stakeholders, especially the city residents, are crucial to the successful adoption and functionality of the designed spaces.

3.2.3 Important values to consider

Designing urban parks requires a nuanced understanding of both ecological and social dynamics. The primary requirements involve ensuring functionality, accessibility, aesthetic appeal, and sustainability. In addition, there are certain values that need to be considered:

Sensory and emotional experience Park design profoundly engages multiple senses, improving the visitor experience. The rustling of leaves, the distinct scents of various plants, and the visual beauty of the landscape all play a role. For visually impaired visitors, scent gardens provide a rich and accessible way to enjoy nature. In addition, incorporating features such as thorny bushes can help manage wildlife within the park, maintaining a balance between natural habitats and visitor safety. The emotional and sensory responses evoked by these elements are crucial for a full appreciation of the landscape.

Functionality and Societal Values Design choices within a park must be both functional and justifiable. For example, areas designated for sports and games, which typically generate a lot of noise, should be strategically placed away from quieter zones intended for relaxation and enjoying nature sounds like birdsong. In addition, every design element should align with ecological and societal values, ensuring sustainability and community benefit. Societal values encompass creating inclusive spaces that cater to diverse groups, promoting social interaction, and fostering a sense of community. This includes providing accessible pathways for people with disabilities, incorporating cultural elements that reflect the community's heritage, and designing spaces that encourage activities for all age groups. Ecologically, the park should support biodiversity, use sustainable materials, and implement green practices such as recycling and water conservation. By integrating these values, the park can become a vital, harmonious part of the urban fabric, improving both the environment and the quality of life of its users.

Balancing subjective and objective values A landscape designer must balance objective and subjective values to create spaces that are functional and aesthetically pleasing. Open spaces may serve practical purposes, but they also offer visual relief and areas for recreation. Similarly, more secluded areas can provide intimate nooks for reflection or bird watching. The interplay of water features, such as flowing streams or ponds, not only supports local ecosystems but also enhances the visual and auditory experience of the park. These design choices, often unnoticed by visitors, are carefully considered by designers to create a cohesive and engaging environment.

Value of a park Recognizing that public spaces belong to everyone can significantly enhance how these areas are used and cared for. When people understand this concept, they are more likely to respect the space, not leaving trash or disputing parking spaces. This sense of shared ownership encourages a more positive and responsible community interaction with the park.

3.2.4 Current trends and challenges

The landscape architect highlighted several challenges in the design of urban parks, including balancing competing land use needs, integrating nature with urban infrastructure, and ensuring long-term sustainability. The current specific challenges are the following two:

Park Rejuvenation Another issue is that the parks need to be rejuvenated. Trees do not live indefinitely; they last between 50 and 200 years. Managing the existing tree population is crucial. The simple removal of old trees is not feasible because once removed, they leave a bare spot that takes years to regenerate with new growth. Parks are often planted in phases, and if all trees from the same period die around the same time, it results in a very bare park. Therefore, it is better to gradually rejuvenate the park to avoid creating dense or bare areas. This approach requires careful planning to refresh the tree population without disrupting the park's overall aesthetics.

Climate change Currently, climate change is a major concern, with heavy rainfall causing flooding in winter and extremely dry conditions in summer. This dryness leads to an increased demand for more trees to combat heat stress. However, the challenge lies in the procurement of water for these trees during dry periods. Finding ways to retain or store water to maintain the greenery during the hot summers is crucial.

3.2.5 Potential PCG Application for Expert

During the interview, the landscape architect was presented with the objective of the investigation. The discussion shifted towards the potential benefits of using a PCG (Procedural Content Generation) algorithm in landscape architecture. However, the expert expressed skepticism, fearing that automated design could result in monotonous and uninspired landscapes. They emphasized the importance of human creativity and intuition in design, believing that a computer would struggle to justify its design choices and understand the emotional impact of green spaces on people.

The conversation delved deeper into the complexities of urban design, highlighting the multitude of conflicting needs and the nuanced decisions required to balance them effectively. The architect questioned how a computer could comprehend the rich emotional experiences that humans associate with urban greenery.

McClure suggests that people who fear new technology are more likely to fear unemployment and financial insecurity [18]. On another note, Mordini suggests that only people who are well educated about new technology know how to make rational decisions about it [19]. It might be interesting to consider that the expert's skepticism could stem from concerns about the potential implications of automated design on their profession. Exploring these concerns in more depth could provide valuable information on the integration of technology in creative fields.

In conclusion, the interview highlighted serious concerns about the use of PCG algorithms in landscape architecture, emphasizing the importance of human intuition and empathy in shaping meaningful urban settings.

3.3 Takeaway

In conclusion, the urban park design process is complex, there are many stakeholders and different values that need to be considered. And also considering the opinion of the experts on PCG it might not be valuable or useful to create a tool for the expert. Instead, a more feasible approach could be to develop a tool specifically for stakeholders without design experience. This tool would engage these stakeholders in the urban park design process, allowing them to contribute meaningfully and ensuring that their input is effectively integrated. This tool would be particularly useful for collecting and incorporating citizen feedback, thereby enhancing community participation in urban park projects.

Chapter 4

Methods and Techniques

This chapter outlines the methodology used in the development and evaluation of the Urban Park Design Tool. The methodology covers the selection of the algorithm, the research on WFC and the development proces until the final prototype.

4.1 Algorithm Selection

Selecting the most suitable algorithm for the tool was a critical step in the development process. The methodology for algorithm selection involved several key steps to ensure a well-informed decision. A comprehensive review of existing procedural content generation algorithms was conducted in Chapter 2. This included studying Modeling Synthesis (MS), Wave Function Collapse (WFC), Markov Junior (MJ), AI and Machine Learning, and Generative AI. The review provided a broad understanding of the capabilities, limitations, and potential applications of each algorithm in the design of urban parks.

The key criteria for the evaluation of the algorithms were established according to the specific needs of the project. These criteria included ease of implementation, flexibility, control over output, and scalability. Each criterion was chosen to reflect the essential qualities required for the successful deployment of the algorithm in the design tool. The algorithms were compared on the basis of established criteria. A detailed comparison table was created to summarize the strengths and weaknesses of each algorithm (see Table 5.1 in Chapter 5). This comparison provided a clear overview of how each algorithm performed relative to the others.

4.2 Research on Wave Function Collapse

To ensure a thorough understanding of the WFC algorithm, extensive research activities were undertaken. This research phase aimed to gather in-depth knowledge about the algorithm's theoretical foundations and practical applications. The study of the WFC algorithm began with an exploration of its theoretical foundations as proposed by Maxim Gumin. This included understanding the principles of superposition and constraint propagation, which are central to the algorithm's operation.

Existing implementations of the WFC algorithm, such as Daniel Shiffman's example, were analyzed to gain insight into different approaches and potential improvements [20]. Reviewing these implementations helped identify best practices and common challenges associated with the algorithm. The available documentation and tutorials were examined to gather comprehensive information on the application of the WFC algorithm in various contexts. This review included studying code examples, detailed explanations, and use-case scenarios to build a robust understanding of the algorithms' capabilities.

4.3 Requirements

The methodology for establishing the requirements for the Urban Park Design Tool is rooted in a systematic and structured approach to ensure comprehensive and prioritized development. This section outlines the process and techniques used to identify, categorize, and prioritize the functional and non-functional requirements of the tool. Based on the information collected in Chapter 2 and Chapter 3 a complete list of requirements was created. Each requirement was assigned a unique identifier for easy reference and categorization. Once the requirements were collected, they were categorized into two main types:

Functional Requirements: These define the specific behaviors and functions of the system. They describe what the system should do.

Non-Functional Requirements: These define the operational capabilities and constraints of the system. They describe how the system should perform its functions.

4.3.1 MoSCoW Method

To prioritize the requirements effectively, the MoSCoW method was used. This method helps to categorize the requirements into four groups:

Must Have (M): Essential requirements that are critical for the system's functionality and cannot be omitted.

Should Have (S): Important requirements that add significant value but are not critical for the initial system deployment.

Could Have (C): Desirable requirements that can enhance the system's functionality but are not essential and can be deferred.

Won't Have (W): Requirements that are agreed upon as the least critical and will not be included in the current project scope.

After categorizing the requirements using the MoSCoW method, the requirements were organized into matrices for better visualization and reference. Two separate MoSCoW matrices were created. The formation of these matrices allows for clear prioritization and helps in focusing on the most critical aspects of the tool's development first.

4.4 Implementation

The tool was developed through an iterative process that emphasized continuous programming and refinement to meet all specified requirements. Initially, a basic prototype was constructed to establish the core functionality. This prototype underwent rigorous testing against the initial requirements, ensuring that both functional and non-functional criteria were addressed. Efforts were focused on integrating required features and ensuring seamless operation. The development cycle systematically addressed challenges, refining algorithms and interface elements to align with project objectives.

4.5 User Evaluation

The effectiveness and potential of the Urban Park Design Tool were evaluated using comprehensive user evaluation methods. This section presents the methodologies and findings of two primary evaluation approaches: an expert interview and a user survey. These methods were used to collect detailed feedback on various aspects of the tool, including its functionality, usability, and impact on the design process. The insights gained from these evaluations are crucial for validating the tool, identifying areas for improvement, and ensuring that it meets the needs of its users. The following subsections outline the objectives, procedures, data collection, and analysis for both the expert interview and the user survey.

4.5.1 Expert User Test

To evaluate the effectiveness and potential of the prototype tool designed for the design of urban parks, an expert interview was conducted. This interview aimed to gather detailed insights into the functionality, usability, and impact of the tool on the design process. The following section outlines the methodology used to conduct the interview.

Objectives and Participants

The expert interview aimed to evaluate the tool's ability to support urban park design, gather feedback on its functionality, and identify areas for improvement. The interview was conducted with a landscape architect to ensure expert feedback.

Interview Design

The interview was structured around an interview guide, which was developed based on the objectives of the evaluation. The guide included general and specific questions to thoroughly assess different aspects of the prototype tool. The interview guide is divided into several key sections: Introduction, Prototype Demonstration, General Questions, Specific Questions, and Conclusion. The entire outline of the interview guide can be found in Abstract D.

Conducting the Interview

The interview was conducted in a semi-structured format using the interview guide as the direction. The process began with an introduction to the prototype, where the expert was given an overview of its features and functionalities. This was followed by a live demonstration of the tool, highlighting key aspects such as customization of park layouts, selection of elements such as water and ground types, and visualization of designs.

After the demonstration, the interview proceeded with general questions to gather initial impressions and assess the tool's usability for beginners. Then, specific questions were asked to dive deeper into particular functionalities, such as customization options and visualization capabilities. Throughout the interview, the expert was encouraged to provide detailed feedback and suggestions for improvement.

Data Collection

Notes were taken during the interview that were later summarized and used for analysis. Mostly open-ended questions were used during the interview to allow for comprehensive feedback and to collect detailed information on how the tool performs. All data collected was analyzed to identify key themes, areas for improvement, and impact.

Conclusion of the Interview

The interview ended with a recap of the main points covered. The expert was invited to share any additional thoughts or suggestions and thanked for their valuable input. Feedback from this interview was crucial in evaluating the current functionality of the prototype and its potential for future application in urban park design.

Ethical Considerations

Ethical standards were upheld throughout the interview process. The expert voluntarily participated, and their anonymity was preserved in the results. Informed consent was obtained before the interview and the expert was briefed on the purpose of the study and the use of their feedback.

4.5.2 Survey

To evaluate the Urban Park Design Tool in another way, a survey was conducted to collect user feedback on various aspects of the tool, including its impact, usability, and overall impression. This feedback is crucial for validation and the identification of areas of improvement.

Objectives and Participants

The survey aimed to determine how useful users found the Urban Park Design Tool to involve stakeholders in the design process. It also assessed the ability of the tool to engage users and encourage collaboration, its effectiveness in facilitating park design, overall user satisfaction, and potential areas for improvement. The participants included a mix of the general public and people working in urban design. The survey was distributed through personal networks, social media and various online groups to ensure a broad range of responses.

Survey Design

The online survey was structured to collect both quantitative and qualitative feedback. It featured a mix of Likert scale questions to gauge user experiences and open-ended questions for detailed suggestions and comments. Participants accessed the tool online to create or modify a park design and then completed the online survey. The survey link was provided on the tool's website and in the invitation to participate, ensuring that participants had practical experience with the tool before providing feedback.

Conducting the Survey

The survey was conducted online using Google Forms, and the participants were directed to a dedicated website where they could access the tool. The process started with participants using the tool to create or modify a park design. Following this, they completed the online survey, which included both a Likert scale and open-ended questions to capture a comprehensive range of feedback.

Data Collection

The data collected from the survey included both quantitative and qualitative responses. For quantitative data, participants rated various aspects of the tool using Likert scale questions. For qualitative data, participants provided detailed suggestions and comments through open-ended questions. This approach ensured a comprehensive collection of feedback regarding the tool's usability and impact.

Data Analysis and Reporting

The collected data was analyzed using both quantitative and qualitative methods. For quantitative data, the mean and standard deviation for each Likert scale question were calculated and summarized using descriptive statistics to reveal overall trends and patterns in user feedback. For qualitative data, a thematic analysis was performed to identify common themes and suggestions. Feedback was classified into strengths, weaknesses, and suggestions for improvement, providing a complete understanding of user experiences. The evaluation findings are summarized in Chapter 6 of this report, including both statistical results and thematic insights. Actionable recommendations based on user feedback were provided to guide future improvements of the tool, ensuring the feedback is not only documented, but also used to enhance the tool's functionality and user experience.

Ethical Considerations

Ethical standards were upheld throughout the survey process. The participants voluntarily participated and their anonymity was preserved in the results. Before the participants accessed the tool, they were informed about the study's purpose and how their feedback would be used.

Chapter 5

Implementation

This chapter presents the implementation of the tool. It covers the study conducted to select the suitable algorithm, insights into how the chosen algorithm operates, the integration of the algorithm into the final prototype, design decisions made for the prototype, and concludes with an overview of the entire final prototype.

5.1 Algorithm Selection

Five different algorithms were discussed in Chapter 2. This section explores the most suitable algorithm for this project by comparing their capabilities and suitability for urban park design. The five algorithms considered are Modeling Synthesis (MS), Wave Function Collapse (WFC), Markov Junior (MJ), AI and Machine Learning, and Generative AI. Each algorithm offers unique benefits and levels of complexity that influence their suitability for different aspects of urban park design. In table 5.1 is a comparison of the three procedural modeling algorithms (MS, WFC, and MJ) along with AI and Generative AI.

Modeling Synthesis (MS): MS is a procedural content generation algorithm that automates the creation of large-scale models based on example-based synthesis techniques. It is known for its simplicity in implementation and its ability to handle various input data, making it an attractive option for urban planners. However, its control over output is limited to constraints on adjacent tiles, which can restrict the complexity of the designs.

Wave Function Collapse (WFC): WFC allows for greater control over the resemblance between the output and the input model by using overlapping patterns. This flexibility makes WFC suitable for creating intricate and aesthetically pleasing urban environments. WFC strikes a balance between ease of use and control over the output, making it a versatile choice for urban park design.

Markov Junior (MJ): MJ is a probabilistic programming language derived from Markov algorithms, capable of creating dynamic and complex models. Its sequential application of rewrite rules allows for significant creativity and flexibility, translating high-level design rules into detailed procedural outputs. While it offers extensive fine-tuning capabilities, it is also more complex and harder to use compared to MS and WFC.

AI and Machine Learning: These algorithms leverage large datasets to generate optimized urban designs by analyzing factors like population density, traffic flow, and environmental impact. AI-driven design processes can significantly enhance the efficiency and quality of urban planning, but they require complex implementation and substantial data.

Generative AI: Representing the frontier of procedural modeling, Generative AI can learn from vast amounts of urban design data to generate new design proposals and simulate urban growth scenarios.

It offers highly detailed and innovative designs, incorporating a wide range of variables and constraints. However, its implementation is very complex and requires advanced computational resources.

Algorithm	**Ease of Implementation**	**Flexibility**	**Control Over Output**	**Scalability**
Model Synthesis (MS)	Easy	Moderate	Limited to adjacent tile constraints	High
Wave Function Collapse (WFC)	Moderate	High	High, with control over overlap patterns	Moderate
Markov Junior (MJ)	Complex	Very High	Very High, with extensive fine-tuning	Moderate
AI and Machine Learning	Complex	Very High	High, with optimization based on large datasets	High
Generative AI	Very Complex	Extremely High	Very High, with creative and innovative outputs	High

Table 5.1: Comparison of Procedural Content Generation Algorithms for Urban Park Design

Considering the balance between implementation complexity, control over output, and flexibility, WFC was chosen for this project. WFC offers a high degree of control and flexibility while remaining more accessible than MJ. It also allows for intricate and aesthetically pleasing designs, which are essential for urban park design. Additionally, WFC's ability to work with overlapping patterns makes it well-suited for creating diverse and dynamic urban environments. The selection of the WFC algorithm for this project is based on its balance of ease of use, flexibility, and control over output. While MS and MJ offer unique advantages, WFC's capabilities align more closely with the project's goals of creating detailed and dynamic urban park designs. AI has not been chosen because of its complexity to implement and the scope of this project.

5.2 Wave Function Collapse Algorithm

The Wave Function Collapse (WFC) algorithm, developed by Maxim Gumin [16], is a procedural content generation technique inspired by the work of Paul Merrell [21]. This algorithm is particularly effective in generating complex patterns and layouts from a set of simple rules and constraints. By iteratively collapsing possible configurations into a definitive layout based on these constraints, WFC facilitates the rapid creation of diverse and coherent designs. The algorithm's name and methodology draw inspiration from quantum mechanics, where "collapse" refers to the transition from a superposition of states to a single state due to measurement. Similarly, in WFC, the algorithm collapses the superposition of possible tile states in a grid to a single definitive tile for each cell, adhering to predefined constraints. This characteristic makes WFC especially valuable in fields such as game design and procedural texture generation.

Figure 5.1: A tile set that can be used for WFC.

5.2.1 Basic Concept of WFC

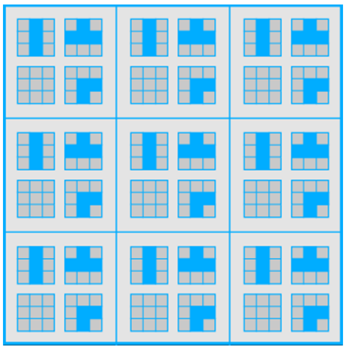
The WFC algorithm operates on a grid where each cell can potentially be any of a set of predefined tiles. Initially, every cell in the grid is in a state of superposition, meaning it could be any tile from the tileset. The goal of the algorithm is to collapse each cell into a single tile in a way that respects the constraints derived from an input example, ensuring that adjacent tiles form valid configurations. A tileset in the context of the WFC algorithm is a collection of predefined tiles, each representing a specific pattern or configuration. These tiles are the building blocks of the generated output. The design of the tileset is crucial as it determines the variety and complexity of possible patterns.

5.2.2 Step-by-Step Explanation

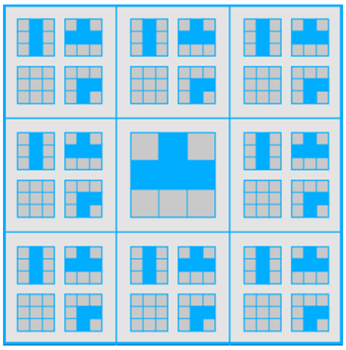
The following steps describe the WFC algorithm process, illustrated by a 3x3 grid example which you can see in Figure 5.2:

1. **Initial Setup**: Begin with a grid where each cell is in superposition, meaning each cell can be any tile from the tileset (Figure 5.2a).
2. **Entropy Calculation**: Calculate the entropy for each cell based on the number of possible tiles.
3. **Tile Selection**: Select the cell with the lowest entropy (i.e., the fewest possible tiles) to collapse next (Figure 5.2b).
4. **Collapse**: Choose a tile for the selected cell and reduce its entropy to zero. Propagate constraints to adjacent cells to update their possible tile options (Figure 5.2c).
5. **Propagation**: Continue the process of collapsing cells with the lowest entropy and propagating constraints until all cells are collapsed into a single tile (Figures 5.2d-f).

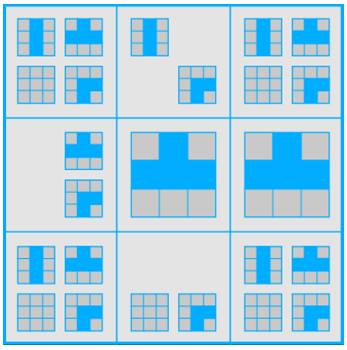
Imagine there is a 3x3 grid that contains tiles from the tile set of Figure 5.1. Adjacent tiles need to match based on the colors. In Figure 5.2 you can see how the algorithm collapses each cell until all the cells are collapsed. Initially, every tile is possible at every cell. The algorithm then picks a random cell and randomly chooses a tile. Then the constraints are propagated and the adjacent tiles are updated. This process continues until all the cells are collapsed.



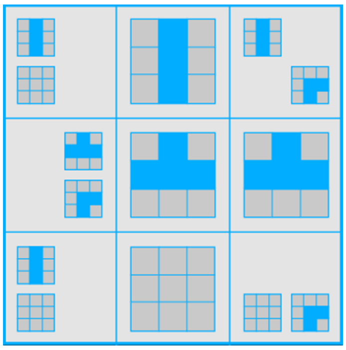
(a) Grid with all options still possible.



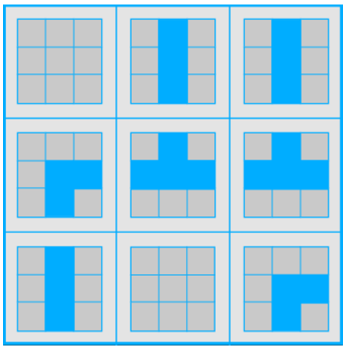
(b) A random option is picked for a random cell.



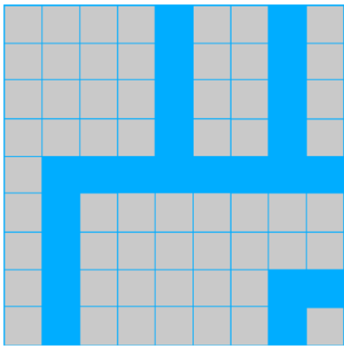
(c) Options of neighboring cells are propagated; collapsed cells are updated.



(d) Next cell is collapsed and options updated.



(e) Grid where all the cells are collapsed.



(f) Result of an entirely collapsed grid.

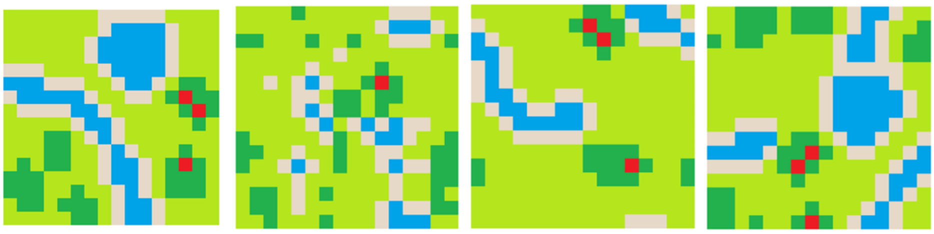
Figure 5.2: Simple breakdown of steps for a 3x3 grid with Wave Function Collapse (WFC).

5.2.3 Overlapping Tiles

To capture more complex patterns, the WFC algorithm can use overlapping tiles of size $n \times n$. Instead of single tiles, the algorithm considers overlapping regions of tiles from the input example. An overlapping tile is an $n \times n$ region of the input example that overlaps with adjacent regions. By sliding a window of size $n \times n$ over the input, all possible overlapping tiles are extracted. These overlapping tiles are used to inform the constraints and ensure that higher-order patterns and dependencies are captured.

Maxim Gumin proposed the overlapping WFC [16]. The adjacency restrictions are replaced with a new constraint that impacts many tiles simultaneously. Each $n \times n$ group of cells in the output must correspond to an $n \times n$ group in a sample grid. This constraint is significantly more sensitive than "simple" adjacency constraints and ensures that the patterns in the sample are replicated in different variants in the output.

As shown in Figure 5.3, different sizes of overlapping tiles (2x2, 3x3 and 4x4) can significantly affect the output patterns. Each sub-figure illustrates how the algorithm captures and replicates higher-order dependencies from the sample.



(a) Sample (b) 2x2 overlap (c) 3x3 overlap (d) 4x4 overlap

Figure 5.3: Sample-based wave function collapse. From left to right: the sample, 2x2 overlap, 3x3 overlap, and 4x4 overlap.

5.2.4 Tile Rotation

An extension to the basic WFC algorithm involves incorporating tile rotations. By allowing tiles to rotate, the algorithm can generate more varied and complex patterns. Each tile can have multiple rotated versions (for example, rotations of 90°, 180°, and 270°). Constraints are updated to consider these rotated versions, increasing the diversity of the generated patterns. For example, a tile with a road segment can be rotated to connect in different directions, allowing for more flexible and varied road networks in the generated pattern.

5.2.5 Summary

The WFC algorithm is a powerful tool for procedural content generation, capable of producing complex patterns based on simple input examples. Using simple tilesets, $n \times n$ overlapping regions, and tile rotations, the algorithm can generate diverse and intricate patterns suitable for various applications. The structured approach of the WFC algorithm ensures that the generated patterns are coherent and aesthetically pleasing, making it a valuable technique in fields such as game design, architectural layout and artistic pattern generation. The insights gained from understanding the WFC algorithm can inform the development of more advanced procedural content generation tools and techniques in the future.

5.3 Requirements

To ensure the effective design and functionality of the Urban Park Design Tool, a comprehensive set of requirements has been established. These requirements are first listed and explained in detail, and then categorized into functional and non-functional requirements. Following this, the MoSCoW method is applied to prioritize these requirements into four groups: Must have, Should have, Could have, and Won't have. This methodical approach ensures that the most critical functionalities are implemented first, while additional enhancements are clearly outlined for future development. The following sections provide a detailed overview of all requirements, followed by the MoSCoW matrices for both functional and non-functional requirements.

5.3.1 Overview of All Requirements

The first step in forming the requirements was to identify all the necessary functionalities and qualities the tool must possess. These requirements were compiled into two main categories: functional and non-functional. Functional requirements define specific behavior or functions of the system, while non-functional requirements describe the system's operational capabilities and constraints.

Functional Requirements

The functional requirements cover the essential actions and features that the tool must support. These include basic functionalities such as tile selection and placement, item selection and placement, constraint enforcement, and the ability to customize tilesets. The complete list of functional requirements is detailed in Table 5.2.

ID	Description
FR1	**Tile Selection and Placement**: The tool allows users to select and place different tiles representing various park ground types.
FR2	**Item Selection and Placement**: The tool allows users to select a tile and place an item on it, such as trees, bushes, structures, etc.
FR3	**Constraint Enforcement**: The tool enforces design constraints based on adjacency rules to ensure valid park layouts.
FR4	**Customizable Tilesets**: The tool allows users to customize the tileset used for park design.
FR5	**Undo/Redo Functionality**: The tool provides undo and redo functionality to allow users to revert or reapply changes.
FR6	**Save and Load Designs**: Users can save their designs and load previous designs for further modification.
FR7	**User Interface for Design**: The tool provides a user-friendly interface for designing urban parks.
FR8	**Tile and Item Locking**: The tool provides the ability to lock tiles and items once a selection is made, ensuring that the algorithm fills the rest of the grid around these locked cells.
FR9	**Export Design**: Users can export their park designs in common formats (e.g., PNG, SVG).
FR10	**Adjustable Tile Quantity**: The tool allows users to change the number of tiles of a specific type that are used.
FR11	**Tile Popup Options**: When clicking on a tile, a pop-up appears with tile options to facilitate easier customization of multiple tiles.
FR12	**Tile and Item Removal**: The tool allows users to remove tiles and items. Removing a tile means that no item can be placed in that cell.
FR13	**Tile and Item Resetting**: The tool provides the ability to reset tiles and items to their initial state.
FR14	**Custom Rule Addition**: The tool allows users to add custom rules, such as ensuring that a bush is always placed next to a flower.
FR15	**Brush Tool**: The tool includes a painting feature that enables users to select a type of tile or item and use it as a brush to quickly apply it to multiple cells.
FR16	**Custom Layouts**: The tool allows users to start with a custom layout of the park.
FR17	**Collaborative Design**: The tool supports collaborative design, allowing multiple users to work on the same park layout simultaneously.
FR18	**Mobile Support**: The tool supports mobile devices.

Table 5.2: Functional Requirements

Non-Functional Requirements

Non-functional requirements ensure that the tool operates effectively and provides a high-quality user experience. These include performance, usability, reliability, and security, among others. The complete set of non-functional requirements is listed in Table 5.3.

ID	Description
NR1	**Performance**: The tool performs efficiently, providing real-time feedback with minimal lag.
NR2	**Reliability**: The tool is reliable with minimal crashes or bugs.
NR3	**Scalability**: The tool is scalable to handle larger park designs without significant performance degradation.
NR4	**Usability**: The tool is easy to use, with an intuitive interface that can be understood by users without extensive training.
NR5	**Documentation**: The tool provides a comprehensive documentation to help users understand and use all features effectively.
NR6	**Theme Customization**: The tool allows users to customize the theme of the interface, including the colors and layout preferences.
NR7	**Security**: The tool ensures that user data are securely stored and protected from unauthorized access.
NR8	**Artificial Intelligence for Design Suggestions**: The tool uses AI to provide design suggestions.
NR9	**Offline Support**: The tool supports offline usage.
NR10	**Interactive Tutorials**: The tool includes interactive tutorials to help new users get started quickly and effectively.

Table 5.3: Non-Functional Requirements

5.3.2 MoSCoW Matrices

To effectively prioritize the requirements for the Urban Park Design Tool, the MoSCoW method was used. This method helps to categorize the requirements into four distinct groups. Must have, Should have, Could have, and Won't have. The aim is to ensure that essential features are identified and implemented first, while additional enhancements are clearly outlined for future development. This systematic approach helps in resource allocation and ensures that the most critical functionalities are delivered to meet user needs and project objectives. The following subsections detail the MoSCoW matrices for both functional and non-functional requirements.

MoSCoW Matrix for Functional Requirements

To prioritize these requirements effectively, the MoSCoW method was applied, resulting in the categorization into Must have, Should have, Could have and Won't have. The functional requirements were organized in Table 5.4 to reflect their priority.

Must Have (M)	Should Have (S)
FR1: Tile Selection and Placement FR3: Constraint Enforcement FR8: Tile and Item Locking FR2: Item Selection and Placement FR13: Tile and Item Resetting FR12: Tile and Item Removal	FR4: Customizable Tilesets FR7: User Interface for Design FR10: Adjustable Tile Quantity FR9: Export Design FR14: Custom Rule Addition
Could Have (C)	**Won't Have (W)**
FR5: Undo/Redo Functionality FR6: Save and Load Designs FR15: Brush Tool FR11: Tile Popup Options FR16: Custom Layouts	FR17: Collaborative Design FR18: Mobile Support

Table 5.4: MoSCoW Matrix for Functional Requirements

MoSCoW Matrix for Non-Functional Requirements

Similarly, the non-functional requirements were prioritized and organized into the MoSCoW matrix shown in Table 5.5.

Must Have (M)	**Should Have (S)**
NR1: Performance NR2: Reliability NR4: Usability NR7: Security	NR3: Scalability NR5: Documentation
Could Have (C)	**Won't Have (W)**
NR6: Theme Customization NR10: Interactive Tutorials	NR8: Artificial Intelligence for Design Suggestions NR9: Offline Support

Table 5.5: MoSCoW Matrix for Non-Functional Requirements

5.4 Implementation of WFC

The implementation of the WFC algorithm in this project is tailored to facilitate the design of urban parks. This section details the specific implementation steps, including grid management, tile and item definitions, constraint propagation, and additional functionalities. The following subsections provide an in-depth explanation of each component and its role in the overall implementation.

5.4.1 File Structure and Environment

The implementation of the Urban Park Design Tool implementation uses HTML, CSS, and JavaScript in combination with the p5.js library. This combination allows for an interactive and visual representation of the WFC algorithm, facilitating the design and manipulation of urban park layouts. The file structure is organized as follows:

File/Folder	**Description**
`index.html`	The main HTML file that sets up the structure of the web application.
`styles.css`	The CSS file for styling the web application.
`sketch.js`	The main JavaScript file where the p5.js setup and draw functions are defined.
`cell.js`	Defines the `Cell` class and related functions for managing grid cells.
`tile.js`	Defines the `Tile` class and related functions for handling tiles.
`item.js`	Defines the `Item` class and related functions for handling items.
`tiles.json`	JSON file containing the definitions and properties of different tiles.
`items.json`	JSON file containing the definitions and properties of different items.
`options.json`	JSON file for additional configuration options.
`assets/images`	Folder containing general images used in the application.
`assets/items`	Folder containing images for the items.
`assets/styles`	Folder containing the `styles.css` file.
`assets/tiles`	Folder containing images for the tiles.

Table 5.6: File Structure of the Urban Park Design Tool

5.4.2 Initialization

When the code is run for the first time, initialization occurs. In p5.js, this is managed by using the `preload` and `setup` functions, which are automatically called once when the program starts. During the initialization phase, the grid, tiles, and items are set up, where the WFC algorithm will be applied.

Initialization involves two primary functions: `preload` and `setup`.

Preload Function The `preload` function is used to load external files before the program starts. This ensures that all necessary data is available when the program begins running. The primary task in the `preload` function is:

- **Loading JSON Data**: JSON files containing definitions and properties of tiles, items, and additional configuration options are loaded. This includes loading images and other resources required for the tiles and items.

Setup Function The `setup` function is called after `preload` and is used to initialize the canvas and other elements. The main tasks in the `setup` function are:

1. **Setting Up the Grid**: The grid, which acts as the design space, is initialized. This involves creating a two-dimensional array of `Cell` objects. Each cell represents a potential placement for tiles and items and is initialized with position coordinates and possible tile and item configurations.

2. **Initializing Tiles and Items**: The tiles and items are instantiated based on the data loaded from the JSON files. This includes setting their properties, such as images and adjacency rules, to ensure they can be properly used in the WFC algorithm.

Grid

The grid represents the design space where each cell can hold a tile and an item. The grid and cells are managed through functions that initialize the grid, reset it, and handle state changes. The grid is defined as a two-dimensional array of cells, each represented by the `Cell` class in `cell.js`, and its size can be set using the `DIM` variable. The grid and cells are initialized to set the stage for the WFC algorithm. Each cell is given coordinates and possible tile and item configurations.

Tiles and Items

Tiles and items are fundamental elements of the design tool, each with specific properties defined in `tiles.json` and `items.json`. Tiles represent ground types, while items are objects placed on top of tiles. Tiles are initialized by loading the JSON structure, which includes information such as image paths and adjacency rules. Similarly, items are initialized using their respective JSON data, ensuring that they are correctly set up for use in the grid.

Each tile and item are instantiated and their properties set, including images and rules, to ensure proper integration into the design tool. These initialization steps collectively prepare the environment for the WFC algorithm, ensuring that all elements are correctly loaded and positioned for the generation of urban park layouts.

Here is an example of a tile definition from `tiles.json`:

```json
{
    "name": "Path Bend",
    "types": ["path"],
    "directions": [
        {
            "direction": "NE",
            "imagePath": "/assets/tiles/ground_pathBend_NE.png",
            "edges": ["GGG", "GPG", "GPG", "GGG"]
        }
    ]
}
```

Listing 5.1: Example Tile Definition from `tiles.json`

Items are initialized in a similar manner. For example, an item definition from `items.json` may look like this:

```json
{
    "name": "Tree",
    "types": ["plant"],
    "directions": [
        {
            "direction": "NE",
            "imagePath": "/assets/items/tree_NE.png"
        }
    ]
}
```

Listing 5.2: Example Item Definition from `items.json`

These JSON files are loaded during the preload phase, ensuring that all necessary data are available before the setup begins. The images specified in the JSON files are also loaded at this stage to ensure that they are ready for use.

By setting up the grid, tiles, and items in this way, the Urban Park Design Tool is prepared to apply the WFC algorithm to generate intricate and visually appealing park layouts.

5.4.3 WFC Application

The application of the WFC algorithm is the core of the Urban Park Design Tool. This section details how the algorithm is applied to generate park layouts that comply with the specified constraints.

Constraint Propagation and Entropy Calculation

Constraint propagation ensures that tiles and items placed in the grid respect the adjacency rules. The entropy of each cell, which indicates the number of possible states it can collapse into, is recalculated as the constraints are propagated. The `Cell` class handles this calculation and manages the entropy of each cell. When a tile or item is placed, constraints are propagated to neighboring cells, reducing their possible options, and updating their entropy. This ensures that the design adheres to the defined rules, maintaining consistency across the grid.

Tile and Item Placement

The placement of tiles and items is managed through two separate applications of the WFC algorithm. Initially, the algorithm focuses on placing tiles across the grid. Each cell is evaluated and tiles are selected based on the lowest entropy, ensuring that the placement adheres to predefined adjacency rules and constraints. The algorithm identifies the cell with the lowest entropy, assigns a suitable tile, and then propagates constraints to neighboring cells, updating their possible options and recalculating their entropy.

Once all tiles have been placed successfully, the algorithm proceeds to the placement of items. The type of tile present in each cell determines the possible items that can be placed on top of it. The placement of items follows a similar process: the WFC algorithm selects cells with the lowest entropy and assigns suitable items that fit the constraints defined by the underlying tile. The constraints are then propagated to adjacent cells to update their possible item options and entropy.

This sequential application of the WFC algorithm for tiles and items ensures that the final design respects all adjacency rules and user-defined constraints, resulting in a coherent and functional urban park layout.

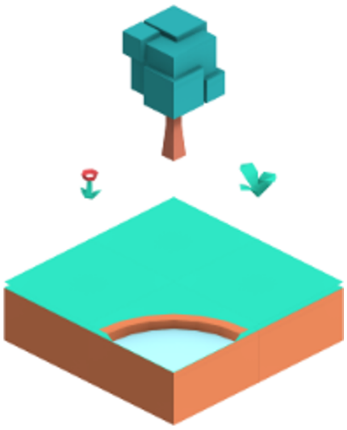


Figure 5.4: Visualization of two output layers of the WFC algorithm.

5.5 Design Concepts

The design of tiles and items for the Urban Park Design Tool underwent several iterations to achieve a functional and visually appealing result. This section describes the evolution of the tile and item designs, from initial experiments to the final implementation.

5.5.1 Initial Design Phase

Initially, the project used tiles from Daniel Shiffman's example of the WFC algorithm [20]. These tiles served as a proof-of-concept to ensure that the algorithm worked correctly within the design tool framework. The tiles used in this phase were simple and generic, primarily focused on testing the algorithm's capabilities rather than aesthetics.

5.5.2 Creating Custom Tiles

After verifying the WFC algorithm's functionality, custom tiles were designed to better suit the project's needs. These tiles were created to represent various ground types, such as grass, dirt, and pathways. The design process involved multiple iterations to ensure that the tiles were visually cohesive and functional within the tool. Figure 5.5 shows examples of these custom tiles.

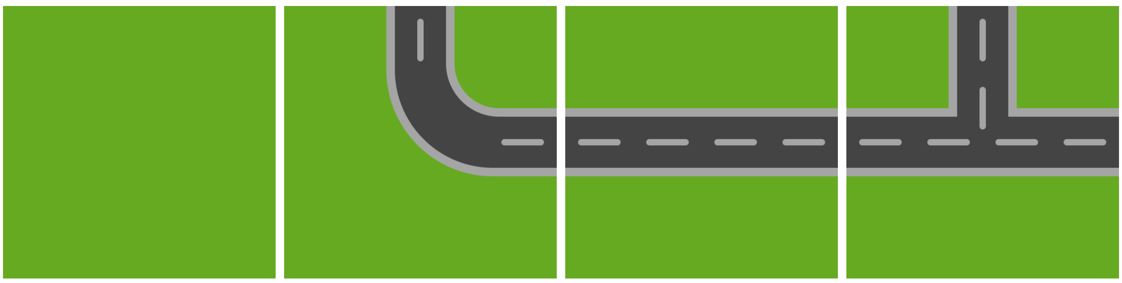
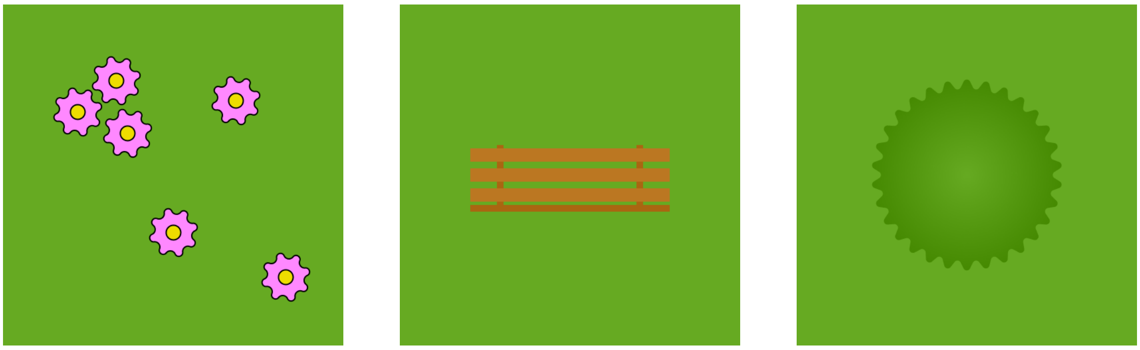


Figure 5.5: Examples of custom tiles created for the project.

5.5.3 Experimenting with Items

Following the development of custom tiles, the next step was to experiment with items. Initially, tiles with items already placed on them were used, simplifying the design process by not requiring a separate array of items. This phase helped to understand the interaction between tiles and items and refine the design tool's functionality. Initially, three item tiles were created, including grass tiles with flowers, benches, and bushes, as shown in Figure 5.6.



(a) Grass tile with flowers (b) Grass tile with a bench (c) Grass tile with a bush

Figure 5.6: Examples of custom items created for the project.

5.5.4 Adopting Isometric Tiles

Recognizing the need for a more realistic and engaging visual representation for novel park designers, the design shifted to isometric tiles. The discovery of Gustavo CP's p5.js implementation of isometric tiles marked a significant change [3]. These tiles, although 2D images, created a 3D effect, enhancing the visual appeal. The implementation of these tiles required careful adjustments to ensure proper alignment and display within the existing 2D grid structure. Figure 5.8 shows these isometric tiles.

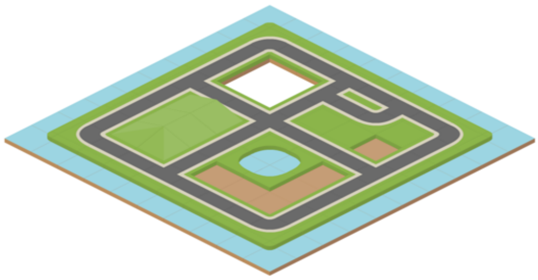


Figure 5.7: Isometric layout [3].

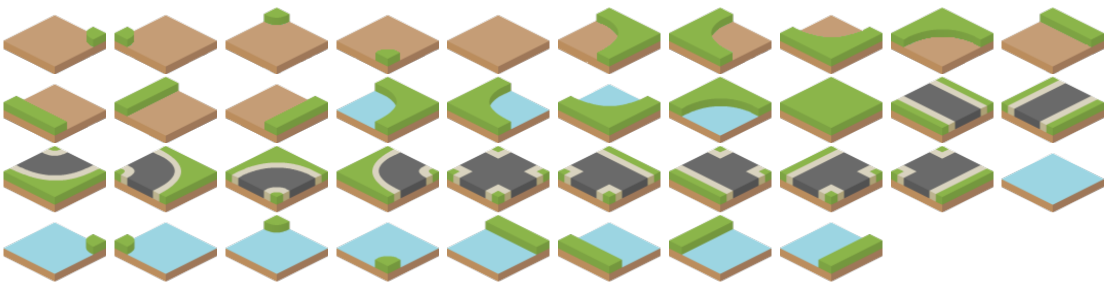


Figure 5.8: Isometric tiles used in the project [3].

The transition from simple 2D tiles to isometric tiles required adjustment in the code to ensure proper alignment and display. Fortunately, the underlying 2D grid structure could be retained, minimizing extensive code modifications.

5.5.5 Final Tile and Item Set

For the final design, the project incorporated tiles and items from Kenney's 3D tileset collection [4]. These assets provided a comprehensive and visually appealing set of tiles and items, including various ground types and items suitable for urban parks. The final tileset offered detailed textures and a variety of elements that improved the overall visual quality of the tool. This tile set is shown in Figure 5.9.

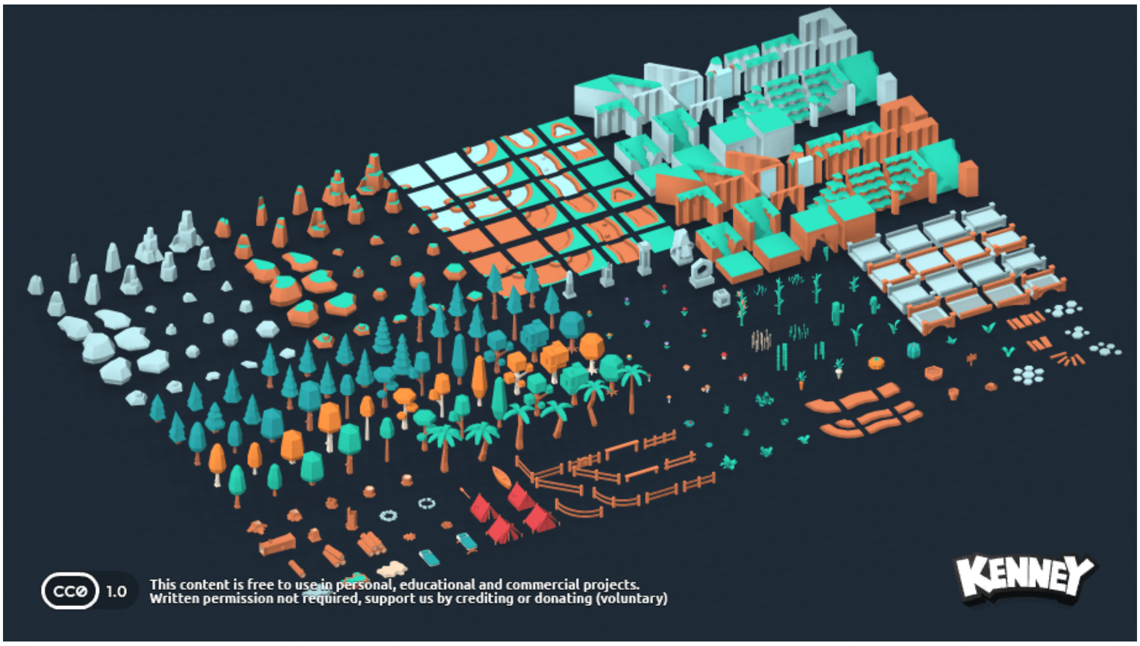


Figure 5.9: Final tiles and items from Kenney's 3D tileset collection [4].

This final tileset, while somewhat limiting in the variety of ground types, offered a sufficient number of items and seasonal variations for trees, perfectly fitting the project's needs without requiring further modifications.

5.5.6 Summary

The iterative design process, from initial experiments to final implementation, was crucial in refining the Urban Park Design Tool. Each phase provided new insights and improvements, leading to a robust and visually appealing design tool specifically tailored for urban park layouts. The combination of custom and isometric tiles, along with detailed items, ensured that the tool was functional and aesthetically pleasing, ultimately achieving the project's goals.

5.6 Final Prototype

The final prototype of the Urban Park Design Tool has been developed and refined on the basis of the requirements and design concepts outlined in the previous sections. The final prototype is hosted under the domain name urbanparkdesign.com [22]. The version control repository is also available on GitHub [23]. This section details the final implementation, its functionalities, user interactivity, and evaluates how well it meets the initial requirements using the Wave Function Collapse (WFC) algorithm.

5.6.1 Implementation Summary

The final prototype includes the following key features:

- **Tile Selection and Placement**: Users can select a cell and choose a tile from a variety of tiles representing different park ground types.
- **Item Selection and Placement**: Items such as trees, flowers, and bushes can be placed on tiles.
- **Constraint Enforcement**: The tool enforces adjacency rules to ensure valid park layouts.

- **Customizable Tilesets**: Users can customize the tileset used in their park design.
- **User Interface for Design**: A user-friendly interface facilitates the design process.
- **Tile and Item Locking**: Tiles and items can be locked to ensure the WFC algorithm fills in the rest of the grid around these locked cells.
- **Tile and Item Removal**: Tiles and items can be removed from the grid.
- **Tile and Item Resetting**: Tiles and items can be reset to their initial state.
- **Custom Layouts**: Users can start with custom layouts for the park.

5.6.2 Functionality and User Interaction

The Urban Park Design Tool is designed to be intuitive and user-friendly, allowing users to create detailed and visually appealing park designs. The following is a detailed description of the tool's functionality and user interaction.

Purpose of the Tool

The primary purpose of the Urban Park Design Tool is to allow users to design urban parks by selecting and placing various ground types and items on a grid. The tool uses the WFC algorithm to ensure that the designs are coherent and adhere to the specified constraints. This tool can be used by urban planners, landscape architects, or community members to contribute ideas and preferences for urban park designs.

User Interface Overview

The user interface of the Urban Park Design Tool is designed to be clear and easy to navigate, providing users with all the necessary tools to create their park designs efficiently. It consists of a grid to place tiles and items, a sidebar to select different elements, and various buttons to perform actions such as generating new designs, resetting the grid, and starting with an empty grid.

Full Page

The full page view of the Urban Park Design Tool shows the layout of the tool, including the main grid, sidebars, and action buttons. Figures C.2 and C.3 illustrate the tool before and after a tile is selected, respectively.

Grid

The main area of the tool is the grid where users place tiles and items. The grid represents the park layout, and users can see the effects of their selections in real time. This interactive grid allows for a dynamic and engaging design process, as shown in Figure C.1.

Left Side of the Screen

The left side of the screen provides users with various options for the ground types, seasons, and categories of items that can be added to the park. These options are accessible through a clear and organized interface, making it easy for users to navigate and select the elements they need. Figure C.4 shows the left side with the different options available.

- **Ground Types**: Users can select from different base tiles like river, water, path, and sand to set the foundation of the park.
- **Seasons**: Users can choose a season (spring, summer, fall, winter) to see the trees in different colors.

- **Categories**: Users can pick items from categories like trees, flowers, benches, and paths to add variety to the park.

Right Side of the Screen (only appears when clicking on a cell)

When a cell is clicked, additional options appear on the right side of the screen, allowing users to choose specific ground types and items to place in the selected cell. This feature ensures precise control over the design elements, as shown in Figure C.4.

- **Tile Options**: Choose different ground types like river, water, path, and sand to create patterns and designs in the park.
- **Item Options**: Pick items such as trees, flowers, benches, and paths to add detail and interest to the park design.

Buttons

The tool includes several buttons to perform various actions, as illustrated in Figure C.5.

- **Generate Button**: Click "Generate" to create a new park design based on the current selections. This button helps explore different layouts.
- **Reset Grid Button**: Use "Reset Grid" to clear the grid and start fresh with default settings. This button includes a tooltip with additional explanation that appears when hovered over.
- **Empty Grid Button**: Click "Empty Grid" to remove all items but keep the ground types, seasons, and categories the same for a blank canvas. This button also includes a tooltip with additional explanation that appears when hovered over.

Tutorial Screen

The tool includes a tutorial screen to guide new users through its features and functionalities. This helps users understand how to use the tool effectively to create urban park designs, as shown in Figure C.6.

5.6.3 Evaluation Against Requirements

The following table evaluates how well the final prototype meets the initial requirements:

ID	Description	Met?	Comments
FR1	Tile Selection and Placement	Yes	Users can select and place various tiles representing park ground types.
FR2	Item Selection and Placement	Yes	Items can be placed on tiles as specified.
FR3	Constraint Enforcement	Yes	The tool enforces adjacency rules for valid layouts.
FR4	Customizable Tilesets	Yes	Users can customize the tileset used in designs.
FR5	Undo/Redo Functionality	No	Undo and redo actions are not supported in the current version.
FR6	Save and Load Designs	No	Designs cannot be saved and loaded in the current version.
FR7	User Interface for Design	Yes	A user-friendly interface is provided.
FR8	Tile and Item Locking	Yes	Tiles and items can be locked for specific placements.
FR9	Export Design	No	Designs cannot be exported in the current version.
FR10	Adjustable Tile Quantity	Yes	Users can adjust the quantity of specific tiles.
FR11	Tile Popup Options	Yes	Clicking on tiles provides customization options.
FR12	Tile and Item Removal	Yes	Tiles and items can be removed.
FR13	Tile and Item Resetting	Yes	Tiles and items can be reset to initial state.
FR14	Custom Rule Addition	Yes	Custom rules can be added.
FR15	Brush Tool	Yes	A brush tool is available for quick application.
FR16	Custom Layouts	Yes	Users can start with custom layouts.
FR17	Collaborative Design	No	Collaborative design is not supported in the current version.
FR18	Mobile Support	Yes	The tool supports mobile devices.
NR1	Performance	Yes	The tool performs efficiently with real-time feedback.
NR2	Reliability	Yes	The tool is reliable with minimal crashes or bugs.
NR3	Scalability	Yes	The tool handles larger designs effectively.
NR4	Usability	Yes	The tool is easy to use with an intuitive interface.
NR5	Documentation	Yes	Comprehensive documentation is provided.
NR6	Theme Customization	Yes	Users can customize the theme of the interface.
NR7	Security	Yes	User data is securely stored.
NR8	AI for Design Suggestions	No	AI for design suggestions is not implemented.
NR9	Offline Support	No	The tool does not support offline usage.
NR10	Interactive Tutorials	No	Interactive tutorials are not available.

Table 5.7: Evaluation of the Final Prototype Against Requirements

5.6.4 Summary

The final prototype of the Urban Park Design Tool successfully meets most of the functional and non-functional requirements. The implementation of the WFC algorithm provides a solid foundation for creating diverse and coherent urban park layouts. The user interface is intuitive, and the tool includes essential features for managing tiles and items, enforcing constraints, and modifying the design. In general, the prototype demonstrates the feasibility and potential of using procedural content generation algorithms, particularly the WFC algorithm, in the design of urban parks.

Chapter 6

Evaluation

In this chapter, the prototype tool designed to assist in urban park design is evaluated. The evaluation was conducted through an interview with an expert. The aim was to gather information on the functionality, usability and potential impact of the tool on the design process. This section provides a summary of the interview results, focusing on the expert's feedback and suggestions for improvement.

6.1 Expert User Test

The expert interview focused on evaluating various aspects of the prototype tool. The expert provided detailed feedback on its current functionality, potential improvements, and overall usability. The expert was introduced to the prototype, which included a demonstration of its capabilities.

6.1.1 Key Findings

The expert user test gave significant information on the strengths and areas for improvement of the prototype tool. This section synthesizes the expert's feedback, providing a detailed analysis of the general impressions, usability, functionality, and potential impact on the design process.

General Impressions

The expert expressed positive impressions of the prototype, noting its potential to involve users in the park design process. The interface was described as user-friendly and visually appealing, which could help to attract novice users to the tool.

Usability

The expert appreciated the interactive elements of the tool, such as the ability to place and modify design elements within the park environment. However, some usability issues were identified. Although the tool allows customization, the expert suggested enhancing this feature to offer more precise adjustments. By, for example, adding more rules for items that are being placed. These rules could be flowers that should not be placed next to large trees because otherwise they will not grow, or placing trees next to other trees to create a grove of tees, etc. Furthermore, although the playful interface is beneficial, the expert noted that more realistic visualization options could help users better understand the scale and impact of their designs. The reason was that people who don't have any urban design experience have a hard time understanding the scale of certain items. Finally, the expert recommended expanding the range of attributes and elements available within the tool to provide a more comprehensive design experience.

Functionality

The expert tested various functionalities and provided specific feedback. The ability to modify the terrain, such as adding water features, was well-received, but limitations in adjusting the quantity and appearance of these features were noted. Placing elements like trees and stones was straightforward, but the expert suggested improvements in handling different types of vegetation and other park features. Additionally, the tool could benefit from a feedback mechanism to help users understand the implications of their design choices.

Impact on Design Process

The expert highlighted the potential of the tool to facilitate greater community involvement in the design process. By allowing residents to experiment with different design elements, the tool can help designers gather valuable input and foster a sense of ownership among community members. This collaborative approach can lead to more effective and accepted design outcomes.

6.1.2 Recommendations for Improvement

Based on the feedback of the expert and the key findings, several recommendations are proposed to improve the tool.

- **Enhance Customization Options**: Allow for more detailed adjustments to design elements.
- **Improve Realism**: Incorporate more realistic visualizations to aid user understanding.
- **Expand Element Library**: Include a wider variety of elements and attributes to enrich the design process.
- **Implement Feedback Mechanisms**: Develop features that provide users with feedback on their design choices.

6.1.3 Summary

The expert user test provided valuable information on the strengths and weaknesses of the prototype tool. The feedback emphasizes the tool's capacity to make urban park design more inclusive by reaching a wider audience. By addressing the identified issues and implementing the recommended improvements, the tool could be refined to better serve its intended purpose.

6.2 Survey

This section presents the findings of the analysis of the survey on the Urban Park Design Tool, which incorporates both quantitative and qualitative methodologies. The answers to the survey can be found in Appendix F.

6.2.1 Quantitative Data Analysis

The quantitative data, collected through Likert scale questions, was summarized using descriptive statistics. The analysis includes the mean and standard deviation for each question, revealing trends and patterns in user feedback.

Descriptive Statistics

These results indicate a generally positive reception of the tool, with users finding it fairly easy to use and effective in helping visualize park designs and facilitating citizen participation.

Question	Mean	Standard Deviation
How satisfied are you with the overall experience of using the tool?	4.00	0.74
How easy was it to understand how to use the tool?	4.08	0.90
How effective was the tool in helping you visualize the park design?	4.17	0.94
How effectively does the tool facilitate citizen involvement in urban park design?	3.92	1.16
How much potential does the tool have to enhance community engagement in urban park design?	4.17	0.94

Table 6.1: Descriptive Statistics of User Feedback

6.2.2 Qualitative Data Analysis

A thematic analysis was performed on qualitative feedback to identify common themes and suggestions.

Common Themes and Feedback

Strengths Useful Features:

- "Different park parts" and "Viewing different park layouts" were frequently mentioned as useful features.
- "Inputting design preferences" was highlighted by several users.

Weaknesses Confusing Features:

- Some users found parts of the interface confusing or difficult to understand.
- Issues with not seeing certain options or boxes in the browser were noted.

Suggestions for Improvement

- Adding tutorials or pop-up guides to help users understand how to use the tool better.
- Enhancing interaction with the map, such as adding zoom functionality.
- Improving color schemes and interface visibility.

6.2.3 Recommendations

Based on user feedback, the following recommendations are proposed to enhance the Urban Park Design Tool:

User Interface Improvements

- Implement a more intuitive and user-friendly interface.
- Add visual cues and pop-up tutorials to guide new users.

Feature Enhancements

- Increase interactivity with the map, including zoom and detailed views.
- Ensure that all options and features are visible and accessible across different browsers.

Color and Design Adjustments

- Revise the color schemes to improve visibility and user experience.

These recommendations aim to address the identified weaknesses and leverage the tool's strengths, enhancing overall user satisfaction and engagement.

6.2.4 Summary

The evaluation of the Urban Park Design Tool, combining both quantitative and qualitative analyses, provides a comprehensive understanding of user experiences and feedback. The insights gained from this evaluation are essential for guiding future improvements, ensuring that the tool continues to meet user needs and facilitate effective community involvement in urban park design.

Chapter 7

Discussion

The development and implementation of the tool have demonstrated the potential of the WFC algorithm in the design of urban parks. This discussion highlights key areas for refinement, user acceptance, and future research directions.

Currently, users can select the tiles they want to use, change the tile of a specific cell, and then regenerate the grid so that WFC fills in the rest, adhering to a coherent design. However, some aspects need to be refined. For example, the placement of trees is currently random, and the expert mentioned during user testing that flowers should not grow immediately next to big trees. Additionally, while users can choose which tiles to use, all tiles are used equally, which can make the output less visually appealing. It would be beneficial to allow users to set the frequency of tiles, so more grass tiles could be used in general, creating a more balanced design.

In addition to the expert user test, a survey was conducted that provided feedback on the usability of the tool. Many users commented on the inefficiency of selecting tiles. The process of clicking on a tile, selecting a new tile, and repeating this for multiple tiles was inconvenient. Improving the user interface to make it more streamlined and user-friendly is essential. For current purposes, adding a bit more realism to the tool would help users better understand the real-life space they are designing. The expert noted that beginner designers often lack spatial correspondence, so making the tool more realistic would be beneficial. The current design uses isometric tiles, which do not require a 3D view, but adding the option to turn the view around might enhance usability.

The algorithm could potentially be optimized to complement traditional design methods rather than replace them. It can aid in the early stages of design by providing a structured starting point, saving designers from starting from scratch, and reducing the likelihood of errors. This can help designers focus on incorporating other important aspects into the design. Future studies could find a tool that could satisfy the designer and validate this approach through more interviews with urban park designers, particularly those in training or early in their careers. However, it is important to consider that some professionals might resist such tools, fearing that they could replace aspects of their work.

Future versions of the tool could incorporate features that address sustainability and ecological impacts, such as water management, biodiversity, and climate resilience. This would align the tool with the goals of contemporary urban planning and enhance its value to designers committed to environmental conservation.

Although the interview provided valuable information, its limitations must be recognized. Feedback came from a single expert, which might not fully reflect the views of all potential users. In addition, the prototype was assessed in a controlled environment, which could differ from real-world usage. These limitations should be kept in mind when interpreting the results and planning future evaluations. Something can also be said about the survey. It provided valuable insights; its limitations must be recognized. Feedback came from a limited number of participants, which may not fully reflect the views of all potential users.

The development of the Urban Park Design Tool, informed by user and expert feedback, highlights its potential in the field of urban park design. By improving constraint management, improving the user interface, improving realism, and addressing user concerns, the tool can better meet the needs of urban park designers. Future research should validate the effectiveness of the tool in professional settings and explore additional features to enhance usability and ecological relevance. This comprehensive approach will ensure the ongoing improvement and relevance of the tool in the design of urban parks.

Chapter 8

Conclusion

Urban parks are crucial to improving urban life by providing recreational spaces, encouraging social interactions, and supporting environmental sustainability. They offer many benefits, such as better mental and physical health, increased biodiversity, and improved air quality. The design of urban parks is a complex task because it involves many stakeholders with different interests and needs. Insights from the expert interview led the focus towards involving citizens in the design process. This involvement ensures that the diverse needs and preferences of the community are taken into account, leading to more inclusive and satisfying park designs. Citizen participation is essential for producing a design that connects with the community and promotes a sense of ownership and satisfaction in people.

The Wave Function Collapse (WFC) algorithm was identified as the most suitable method for this project. Its ability to generate diverse and coherent layouts based on input constraints makes it very adaptable for urban park design. The flexibility and control provided by the WFC algorithm are useful for creating intricate and visually appealing layouts that meet specific design requirements. Using an isometric tileset was discovered to be the most straightforward approach, resulting in a visually appealing 3D effect that improves the user experience. The isometric perspective enhances the park layout by adding depth and realism, making it both interesting and functional.

The developed tool goes beyond simple layout generation by including interactive components that allow users to influence design decisions. The WFC algorithm then uses these user inputs as new constraints, ensuring that the final design is consistent with the user's choices. This interaction allows users to actively participate in the design process, resulting in a more personalized and satisfying output. The tool was well received by both the expert and survey respondents, who praised its functionality and user interface.

In conclusion, this study demonstrates the feasibility and usefulness of applying the WFC algorithm to urban park design, while underlining the need for additional development and improvement to fully realize its potential. Incorporating interactive design components and community interaction means that the tool not only creates layouts, but also promotes a collaborative and inclusive design process.

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Appendix A

Generative AI Policy

During the preparation of this work, the author used ChatGPT in order to formalize some of the text written in this report. After using this tool/service, the author reviewed and edited the content as needed and takes full responsibility for the content of the work.

Appendix B

Expert Interview

B.1 Interview Guide

B.1.1 Interview Schedule

Time	Title	Description
11:00	Introduction	Start the interview with an introduction, providing an overview of the research project and its objectives.
11:05	General questions	Begin with the general questions to gather background information about the interviewee's role and daily responsibilities.
11:15	Specific questions	Proceed with the more specific questions to explore detailed aspects of the design process and the tools used.
11:25	Open discussion	Start an open discussion to allow for any additional insights, comments, or questions from the interviewee.
11:30	Close interview	Close the interview by summarizing key points discussed and thanking the interviewee for their time and participation.

Table B.1: Interview Schedule

B.1.2 Introduction

My name is Sterre Kuijper, and I am currently in my final year of my Bachelor's in Creative Technology. I am working on my graduation project, which focuses on the design process of urban parks and explores how a computer tool can support designers in the early stages. This tool is intended to provide designers with a starting point, so they do not have to begin entirely from scratch, and to assist them during the brainstorming phase. This makes it easier to clearly present the requirements and show a proof of concept to stakeholders.

B.1.3 General Questions

1. What does your role involve exactly?
2. What are your daily responsibilities?
3. What are the biggest challenges you face as a landscape architect when designing urban parks?
4. How do you ensure that a park meets both the ecological and societal needs of the community?
5. Can you provide examples of successful urban park projects you have worked on? What made these projects successful?

6. Who are the key stakeholders you consider during the design process?
7. How do you incorporate community feedback into the design process?
8. What current trends do you see in urban park design?

B.1.4 Specific Questions

1. At which stage of the design process do you need the most support or tools?
2. What tools do you currently use during the design process?
3. Do you see potential in using a computer-assisted tool to improve the urban park design process? If so, what functionalities would you consider essential in such a tool?
4. How important is it for you to quickly generate and evaluate different design options in the early stages of the design process?
5. What specific requirements or constraints are crucial to consider when designing urban parks in our municipality?
6. How would a tool that automates the design process affect your work? Would you perceive this as positive or negative?
7. Do you think a tool using the Wave Function Collapse algorithm would be effective in addressing the complexities of urban park design?

Appendix C

Final Prototype

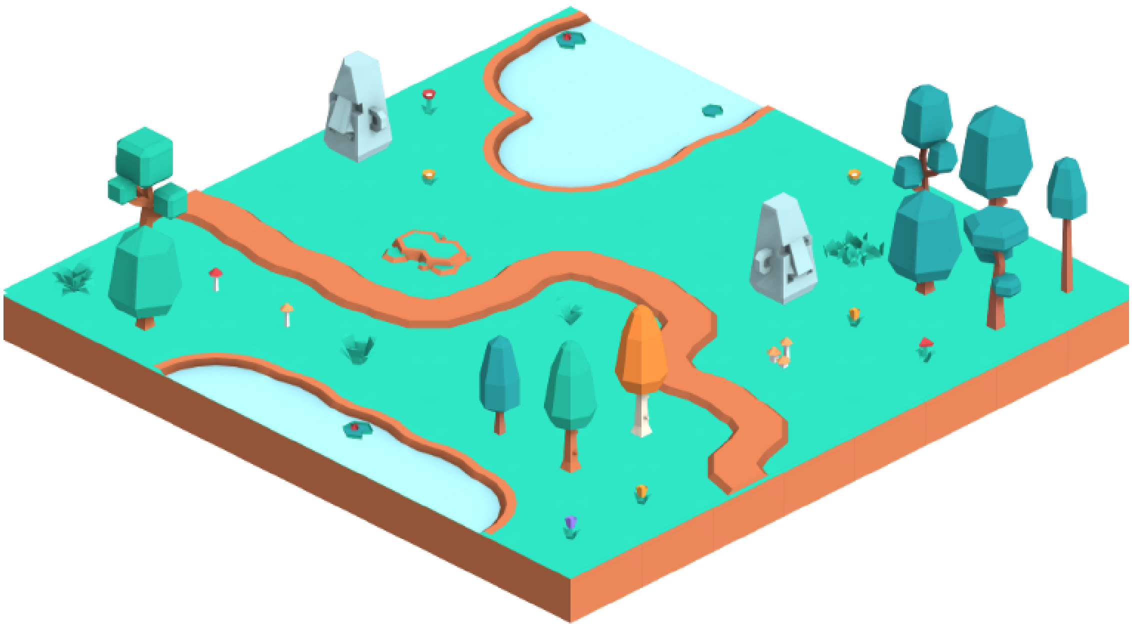
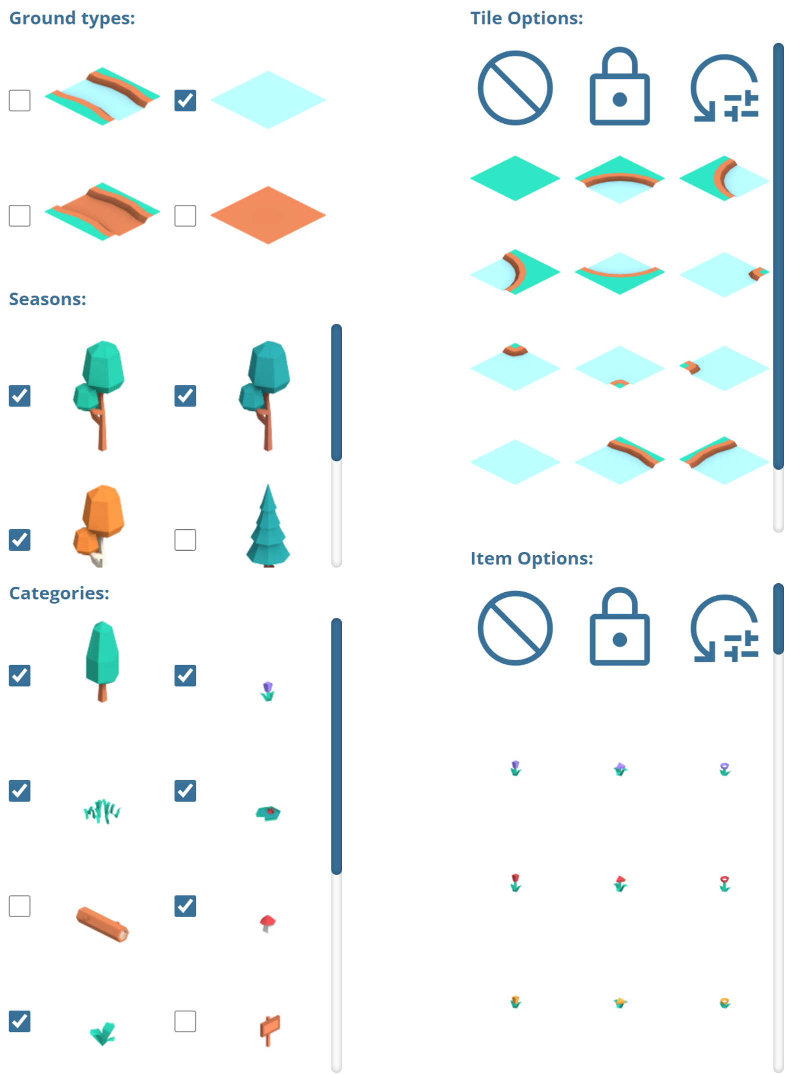


Figure C.1: Grid and output view of the tool.

Figure C.2: Full page view of the Urban Park Design Tool.

Figure C.3: Full page view of the Urban Park Design Tool when a tile is selected.



(a) Left side of the screen showing ground types, seasons, and categories.

(b) Tile and item options available when clicking on a cell.

Figure C.4: Left and right side of the screen.

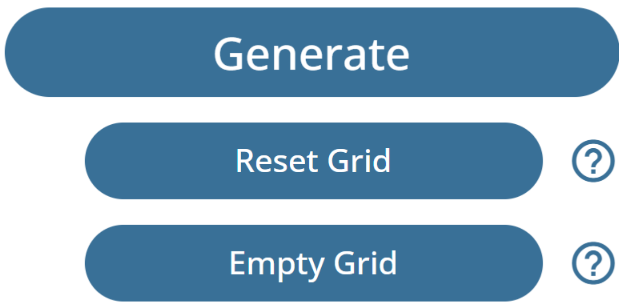


Figure C.5: Buttons for generating, resetting, and emptying the grid.

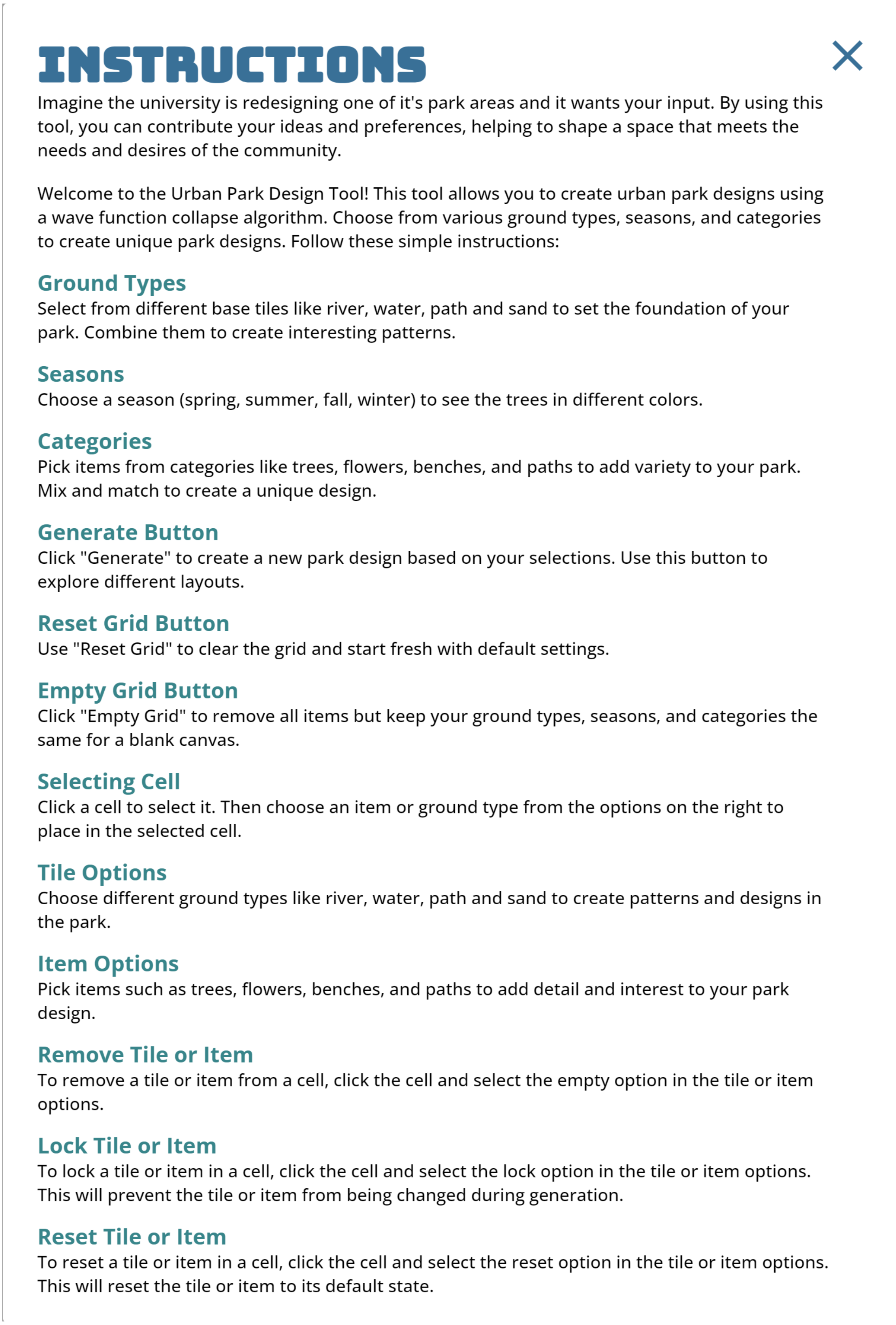


Figure C.6: Tutorial screen of the Urban Park Design Tool.

Appendix D

Expert User Test

D.1 Interview Guide

D.1.1 Interview Schedule

Time	Title	Description
15:00	Introduction	Start the interview with an introduction, providing an overview of the prototype and its current capabilities.
15:10	Prototype Demonstration	Demonstrate the prototype, highlighting key features and functionalities.
15:20	Initial Impressions	Ask the interviewee for their initial thoughts and impressions on the prototype.
15:25	General Questions	Discuss the overall functionality, usability, and user engagement of the tool.
15:40	Specific Questions	Explore specific aspects of the tool such as customization, visualization, and practicality.
15:55	Conclusion	Summarize the key points discussed and thank the interviewee for their participation.

Table D.1: Interview Schedule

D.1.2 Introduction

Begin the interview by providing an overview of the prototype and its intended purpose. Explain that the tool is designed to assist in urban park design by allowing users to customize park layouts, select various elements, and visualize their designs. Highlight the aim of gathering feedback to assess the tool's functionality, usability, and overall effectiveness.

D.1.3 Prototype Demonstration

Demonstrate the prototype to the interviewee. Start by showing how to customize park layouts, explaining the process of selecting different elements such as water features and ground types. Highlight how users can visualize their designs, providing examples of the tool's capabilities. This demonstration should give the interviewee a clear understanding of how the tool works and its current features.

D.1.4 General Questions

Initial Impressions

- What are your initial thoughts on the prototype?

- How user-friendly does the interface appear to you?

Usability for Beginners

- How suitable do you think the tool is for novice park designers?
- Are there any aspects that might be too complex for beginners?
- What additional support or guidance could help new users?

User Engagement and Feedback

- How well does the tool engage users in the design process?
- What features could be added to better collect feedback from stakeholders?

Overall Functionality

- How well does the tool support the initial stages of park design?
- What practical considerations (e.g., sustainability, maintenance) are currently lacking?
- What additional functionalities would enhance the tool's practicality?

D.1.5 Specific Questions

Customization and Flexibility

- How do you find the customization options for different park elements?
- Were there any features that did not work as expected?
- What improvements would you suggest for the customization functionalities?

Visualization and Realism

- How effective are the current visualization capabilities of the tool?
- Do the design outputs appear realistic enough for professional use?
- How could the visualization aspects be improved?

D.1.6 Conclusion

Conclude the interview by summarizing the key points discussed. Recap the main feedback and suggestions provided by the interviewee, highlighting areas for improvement and any positive aspects noted. Ask if there are any additional comments or suggestions they would like to add. Finally, thank the interviewee for their time and valuable feedback, and explain how their input will be used to assess the potential of the prototype.

Appendix E

Evaluation Survey

E.1 Survey Questions

Introduction

Thank you for participating in this survey about the Urban Park Design Tool.

This tool is designed to involve citizens in the design process of urban parks. Your feedback is crucial in helping understand how effective the tool is and what impact it has. Whether you are a professional, a community member with a passion for gardening, or someone with no prior design experience, your input is valued.

For example: Imagine the university is redesigning one of it's park areas and it wants your input. By using this tool, you can contribute your ideas and preferences, helping to shape a space that meets the needs and desires of the community.

This survey should take approximately 5-10 minutes to complete.

Instructions

Before filling out the survey, please take a few minutes to try out the Urban Park Design Tool. Here's how you can get started:

1. **Access the Tool**: http://urbanparkdesign.com/
2. **Explore Features**:
   - **Input Design Preferences**: Enter your ideas and preferences for the park design. You can delete tiles or select a specific tile.
   - **View Park Layouts**: See different layout options based on your inputs.
   - **Make Changes**: Keep parts that you like and further input your preferences.
3. **Spend at least 5 minutes** exploring the tool to get a feel for its functionality.
4. **Note Your Impressions**: Pay attention to what you find easy or difficult, and any features you particularly like or dislike.

Once you've tried out the tool, please return to this survey and provide your feedback. Your input is invaluable in helping evaluate the tool.

General Information

- What is your age?
  - Under 18
  - 18 - 24

- 25 - 34
- 35 - 44
- 45 - 54
- 55 - 64
- 65 and older

- Have you ever been involved in any type of design or landscaping project? (Select all that apply)
  - Professional urban park design
  - Community garden design
  - Personal garden decoration
  - School or educational project
  - None of the above
  - Other...

Usability and Experience

- How satisfied are you with the overall experience of using the tool?
  Linear scale: 1 (Very Dissatisfied) to 5 (Very Satisfied)
- How easy was it to understand how to use the tool?
  Linear scale: 1 (Very Difficult) to 5 (Very Easy)
- How effective was the tool in helping you visualize the park design?
  Linear scale: 1 (Very Ineffective) to 5 (Very Effective)
- How likely are you to recommend this tool to others involved in park design?
  Linear scale: 1 (Very Unlikely) to 5 (Very Likely)
- How much potential does the tool have to enhance community engagement in urban park design?
  Linear scale: 1 (No Potential) to 5 (High Potential)
- How effectively does the tool facilitate citizen involvement in urban park design?
  Linear scale: 1 (Not Effective) to 5 (Highly Effective)

Feedback and Suggestions

- Which features did you find most useful? (Select all that apply)
  - Deleting tiles
  - Inputting design preferences
  - Viewing different park layouts
  - Keeping the parts that you liked
  - Other...
- Were there any features that you found confusing or difficult to use?

  ____

- Do you have any suggestions for improving the tool?

  ____

Appendix F

Evaluation Survey Results

F.1 Closed questions

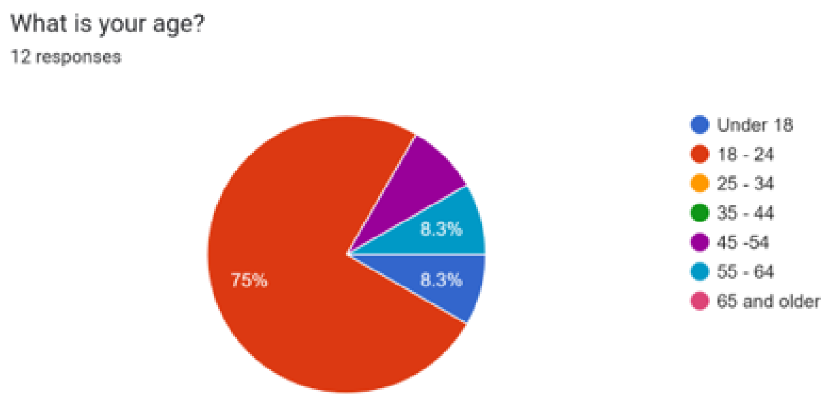


Figure F.1: Caption

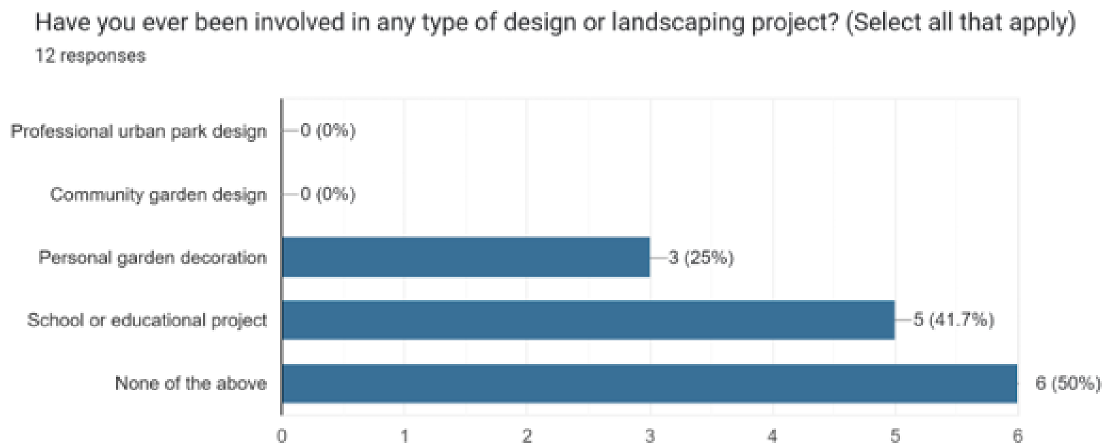


Figure F.2: Caption

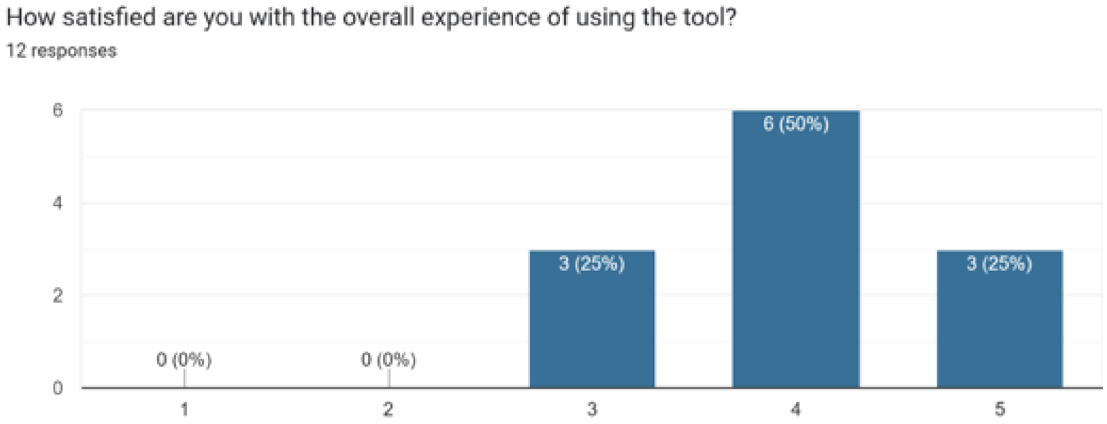


Figure F.3: Caption

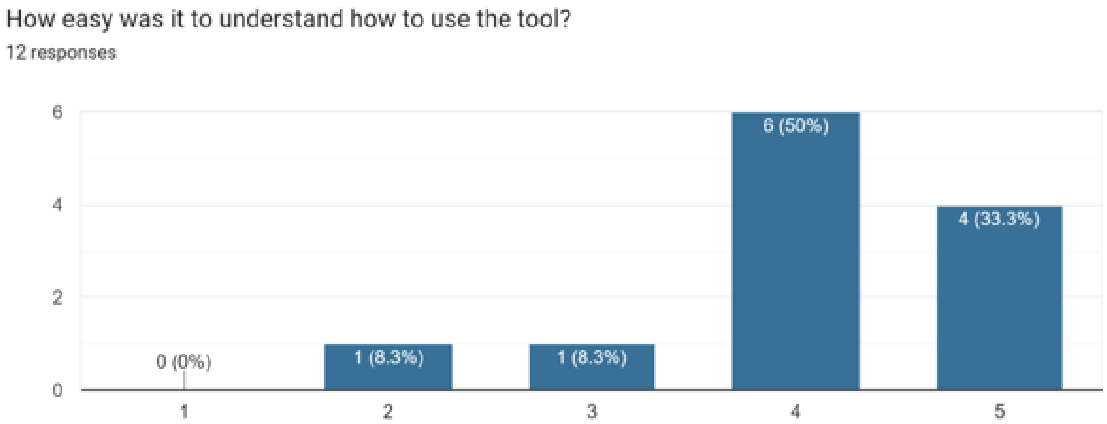


Figure F.4: Caption

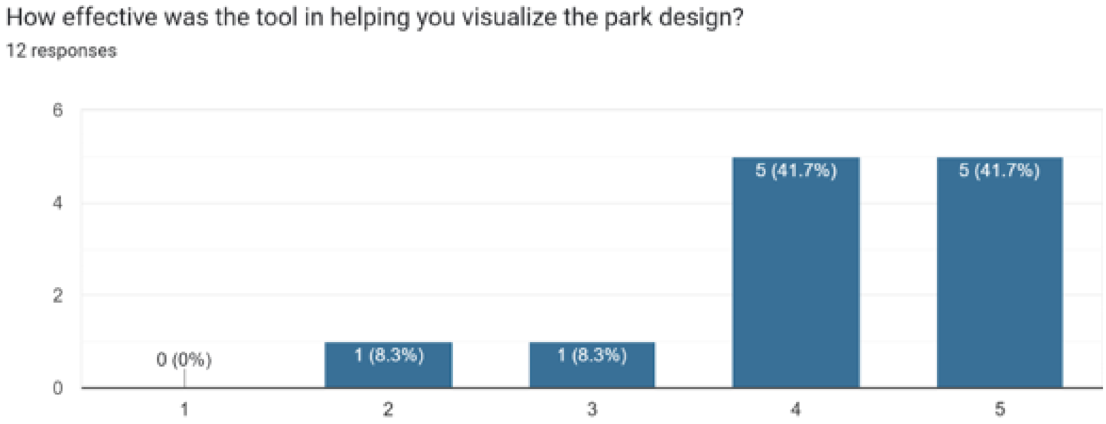


Figure F.5: Caption

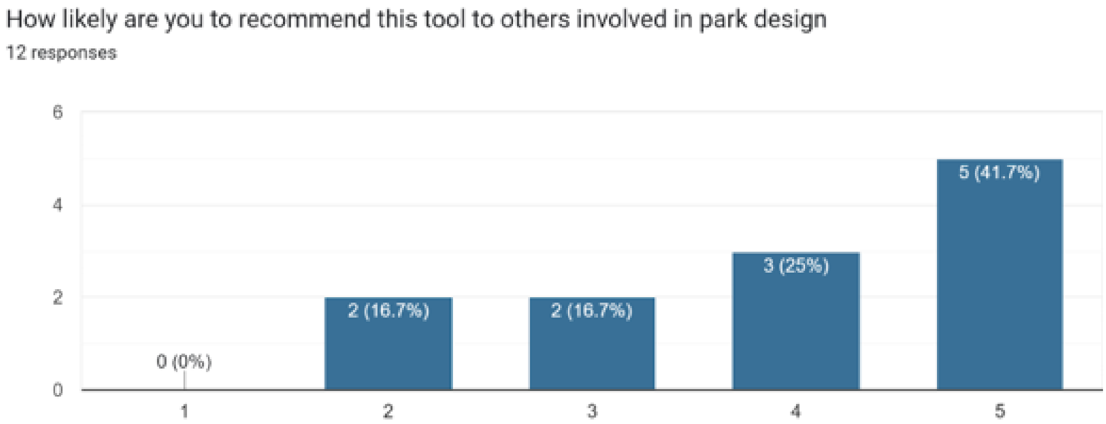


Figure F.6: Caption

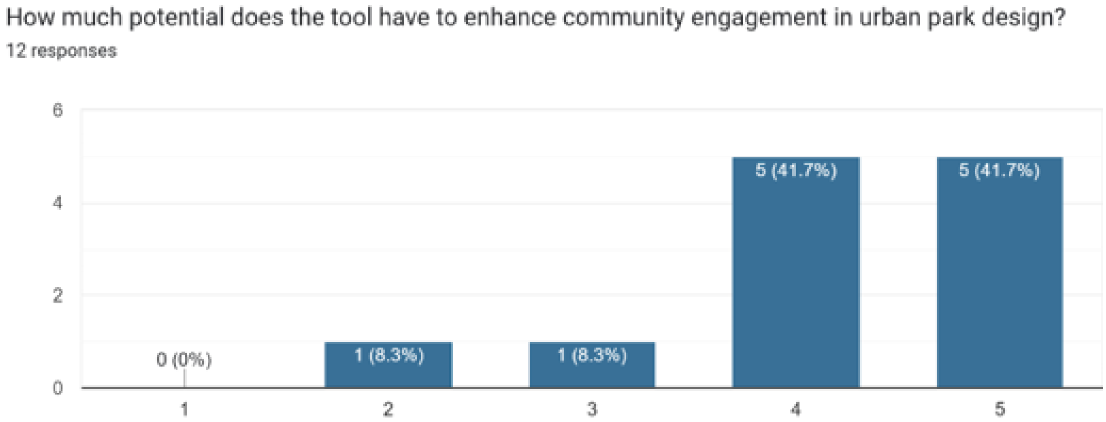


Figure F.7: Caption

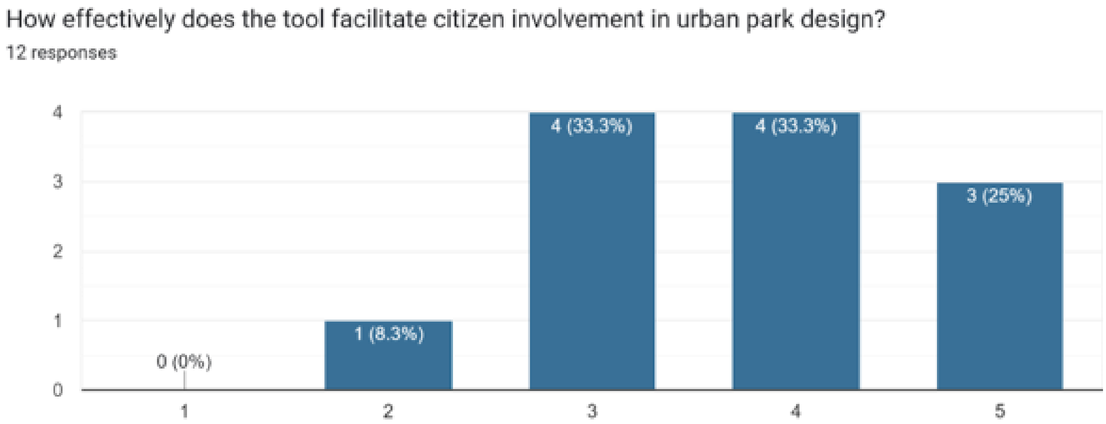


Figure F.8: Caption

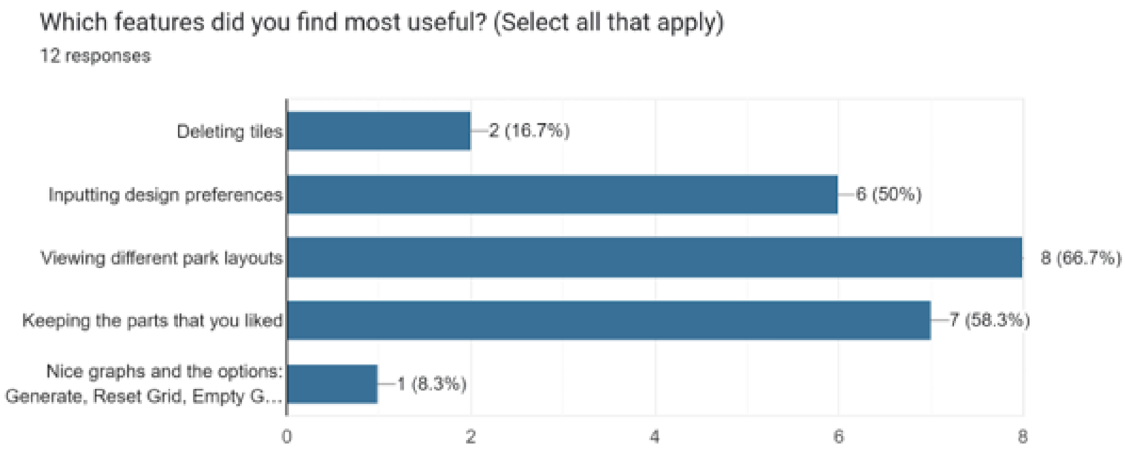


Figure F.9: Caption

F.2 Open questions

Were there any features that you found confusing or difficult to use?
Some parts were not available in some combinations
I do not understand most of the interface on the right. What is a cell different from an item, what do the water lilies do and why do they lock a cell when you put one on it?
-
I didn't see initially the options for the different seasons
In the browser I could not see any of the boxes on the left side. Ground types had just 4 checkmarks without any idea what it stands for.
Not really
Sometimes when I generated another layout it kind of got stuck and only generated a couple of blocks, furthermore the 'reset the cell' function merely unlocks it and does not change it back to its current state which I thought it would do
No, it was very easy to use and understand
Not really
x

Table F.1: Features that were found confusing or difficult to use

Do you have any suggestions for improving the tool?
Change colors
I think adding a popup with a short tutorial about the interface and its options would really help make the tool more accessible. Also making users aware of a design goal or the constraints would be nice, as that is the added value over just a minecraft-like block builder.
I would like to have the ability to watch a short video instruction, to get you started
Maybe more interaction with the map, like zoom and 3D rotation
Once you click on a tile, suggestions for that tile pop up on the right top side, it might be nice to have this as a hover on the tile itself, so that you can create tiles quicker. Right now with this grid it would take ages to fill in the whole map
Maybe first let the code find a possible layout and then generate the image, instead of being stuck in a generating loop because I selected too many preferences the tool had to take into account. If the tool is stuck in the background finding a solution to a layout, a text could suggest the user to decrease their selected preferences and let the tool inspire them.
I felt like, when I generated park layouts, the generator tended to either place a lot of river or path tiles, which removed the feeling of it being a park. It would be nice to have a function where you can have as input the number of tiles you want of that specific theme.
No
Maybe more options for also 3D pictures
x

Table F.2: Suggestions for improving the tool