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Computer-Aided Modeling In Parametric Landscape Design*

Parametrik Peyzaj Tasarımında Bilgisayar Destekli Modelleme

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Abstract

In this study, the possibilities of using parametric design in landscape architecture are examined through the design process and design elements. Three different computer-aided design programs, which play an important role in parametric design, were compared and the more advantageous program for parametric design was selected. Examples designed using parametric design approach and design principles are examined and the use of parametric design in landscape architecture is emphasized. At the end of the study, the application of parametric design in landscape design is discussed on the basis of problem-solution and form-logic relationships.

Keywords: Parametric Landscape Design, Design Process, Computer Aided Modeling

Özet

Bu çalışmada parametrik tasarımın peyzaj mimarlığındaki kullanım olanakları tasarım süreci ve tasarım öğeleri üzerinden incelenmiştir. Parametrik tasarımda önemli rol oynayan bilgisayar destekli tasarım araçlarından üç farklı program karşılaştırılarak, parametrik tasarım için daha avantajlı olan program seçilmiştir. Parametrik tasarım yaklaşımı ve tasarım ilkeleri kullanılarak tasarlanmış örnekler incelenmiş ve bu hususlarda parametrik tasarımın peyzaj mimarlığındaki kullanımı vurgulanmıştır. Çalışmanın sonunda, parametrik tasarımın peyzaj tasarımında uygulanma şekli, problem-çözüm ve form-mantık ilişkileri temelinde tartışılmıştır.

Anahtar Kelimeler: Parametrik Peyzaj Tasarımı, Tasarım Süreci, Bilgisayar Destekli Modelleme

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1. Introduction

Landscape architecture is a discipline aimed at regulating interactions between the natural environment and human beings by creating aesthetically pleasing and functional spaces. The design process in this field is often complex, involving consideration of various and variable parameters. In recent years, parametric design has become increasingly prevalent as a method to alleviate the challenges in landscape architecture design processes. This approach offers a framework where design parameters can be flexibly adjusted, diverse design options can be rapidly generated, and environmental sensitivities can be maintained.

The parametric design approach is a design methodology based on determining design parameters, defining their relationships, and automatically generating designs based on these parameters. In this approach, the design process begins with designers creating a parameter model, where they input values for a set of variables and define their relationships. These parameters can include various features such as dimensions, material selection, geometry, tolerances, and more. Once the parameters are set, the parameter model is run through software that automatically generates the design. This software recalculates the design based on the values of the specified parameters, and altering each parameter results in a change throughout the entire design.

Today, parametric design technology has become widely used in landscape architecture, paralleled by the growing importance of computer-aided design software. The use of design programs like Rhino based on Grasshopper provides several advantages over traditional design, allowing for efficient selection of structural forms through different parametric variations, facilitating detailed component data for analysis, and enhancing interdisciplinary communication efficiency.

The aim of this study is to explore the possibilities of using parametric design tools in landscape architecture. By examining the features and capabilities of computer-aided modeling tools in parametric landscape design, the study seeks to identify a more suitable tool for parametric design. The objective is to apply parametric landscape design principles to a proposed area using these tools. The use of parametric design in landscape architecture will be examined based on criteria such as problem-objective in design, type of design service, and the application of parametric design thinking in design stages. This will elucidate the effects of parametric design on the landscape design process and its impact on landscape design elements.

Computer-aided design/modeling tools play a crucial role in parametric design. They enhance efficiency and flexibility in the design process, allowing for rapid modifications and adaptations. The study will compare three different design tools based on various considerations, aiming to select the most advantageous tool for parametric design.

1.1. Elements Constituting the Parametric Design Process

Sevgi (2013) defined the formation process of parametric design with four components: initial conditions and parameters, methods for generating variables (output, product), generation mechanism (rules, algorithms), and the selection of the optimal variable. The parametric design process continues with the production of variables within the framework of rules and algorithms, where the initial conditions and parameters specified by the designer are interrelated. In this process, the most suitable variables are selected to form the design object (Sevgi, 2013).

The elements constituting the parametric design process are as follows (Sevgi, 2013):

Initial conditions and parameters (Inputs): These are variables that form the starting point of the design and are used throughout the design process.

Methods for generating variables (Output, Product): These enable the determination of variables to be used in the design process, based on the initial conditions and parameters.

Generation mechanism (Rules, Algorithms): This expresses the relationships and dependencies among variables through rules and algorithms.

1.2. Algorithm of Parametric Design Model

The creation of a parametric design model in landscape architecture involves three stages:

Definition of Parameters Based on Data: For instance, Hammad (2020) outlined various parameters for the design of a pocket park, including dimensions/scale, area selection, accessibility, function, park boundary, location type, terrain, plant cover, etc. Adjustable data in park design. Additionally, Hammad (2020) compiled the quantitative standards of the design as a database for defining design rules. Different data is collected for different landscape designs, and desired parameters can be established.

Determination of Design Rules: The most crucial aspect of parametric design is the determination of rules. A specific design algorithm is conceived for a design and transferred to computer-aided programs. This requires a thorough understanding of computer-aided modeling tools by the designer.

Attainment of Design Results: In parametric design, diverse and quickly obtainable results are expected. The outcome represents the success of both human cognition and computer algorithmic calculations.

In summary, parametric design in landscape architecture consists of the following stages: Identification of initial conditions and parameters; Generation of variables defined by the designer through rules; Optimization of output and output product.

1.3. Principles of Parametricism / Parametric Design

The term "Parametricism" is used to describe an approach in design and architecture. This approach refers to designs created through the use of computer-aided design and production technologies to shape and produce complex geometries and structures. The term "Parametricism" was introduced by Patrick Schumacher of Zaha Hadid Architects in 2008. Schumacher promoted this approach to enhance the use of computer-aided production technologies in architectural design, allowing designs to achieve a level of complexity in geometries that was previously unattainable. Parametricism also enables design to be modeled and modified through mathematical formulas and parameters.

Schumacher asserts that parametricism emerged from the creative development of parametric design systems aimed at explaining the workings of complex social processes and institutions (Schumacher, 2009). According to Patrick Schumacher, parametricism is the most important movement following modernism. As with every movement, Patrick Schumacher defines principles that should be followed and elements that should be avoided in parametricism. Schumacher outlined these principles at different times, particularly in the 2008 publication "Parametricism as Style - The Parametricist Manifesto," the 2009 publication "Parametricism: A New Global Style for Architecture and Urban Design," and the 2011 book "The Autopoiesis of Architecture." These principles are organized into two categories: affirmations (dogmas) and rejections (taboos).

In recent studies, the principles proposed in the Parametricist Manifesto have been grouped under common headings by gathering similar conditions together, thereby defining key characteristics to look for in designs. In a study by Oktan (2015), the affirmations and rejections deemed necessary for evaluating parametric designs within the context of the "Parametricist Manifesto" are organized as shown in Table 1 below (Table 1).

Table 1. Affirmations / rejections formulated within the context of the "parametricist manifesto".

	Principles of the Parametricist Manifesto	Formulated Principles
Dogmas	▪ Articulation ▪ Interconnection of all systems	**Interrelation**
	▪ Hybridization ▪ Morphing ▪ Deformation ▪ Systematic bending and interconnection ▪ Differentiation of all systems within certain rules	**Differentiation of form**
	▪ Variation and repetition of the same unit ▪ Repetition with variation in different proportions	**Differentiated repetition**
	▪ Use of NURBS ▪ Use of splines (curved lines)	**Curvilinearity**
	▪ Use of coding ▪ Parametric processing of all forms	**Parametric design**
	▪ Decontextualization	**Universality**
Taboos	▪ Conventional typologies ▪ Platonic forms ▪ Sharp edges ▪ Straight lines ▪ Right angles and corners ▪ Rigid geometric shapes like squares, triangles, and circles ▪ Rigid forms	**Euclidean forms**
	▪ Lack of interrelation ▪ Juxtaposition of unrelated sub-parts and systems ▪ Unrelated individual parts ▪ Unrelated sub-parts	**Lack of interrelation**
	▪ Simple repetition of the same unit ▪ Simple repetition of parts ▪ Simple repetition of sub-parts	**Simple repetition**

2. Material and Method

2.1. Material

In the scope of this study, an initial literature review was conducted to investigate fundamental information that could be utilized in the research. Among these fundamental pieces of information are the concept of parametric design, elements constituting the parametric design process, parametric design principles, landscape design process and elements, the concept of computer-aided design, and modeling tools. In the subsequent stages, the application of the parametric design approach and the use of parametric design principles in landscape design were elucidated by examining examples of landscape design where parametric design principles were employed. Concurrently, a comparison of computer-aided modeling tools was carried out to highlight the advantages and disadvantages of programs deemed suitable for parametric design. The cited landscape examples in the research encompass fifteen cases, namely Curvilign Bench(Anonymous, 2015), LightPRO Shell Pavilion(Pintos, 2022), Urbach Tower(ICD/ITKE, 2019), Please Be Seated (Paul Cocksedge Studio, 2021), Stadel Museum(Gooood, 2014), Light Wall House (EcoLogic Studio, 2012), Bench Layout(Anonymous, 2023), Roche Campus Kaiseraugst (Bryum, 2019), Parametric Space Installation(Gooood, 2016), Children's Playground(L&A Design, 2020), The South Park(Fletch Studio, 2017), Keio University(MDP, 2012), Sony Forest(Groundhog, 2012), Edaphic Effects(Groundhog, 2011), and MAX IV Laboratory Landscape(Groundhog, 2016).

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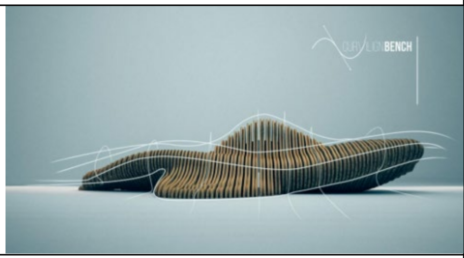
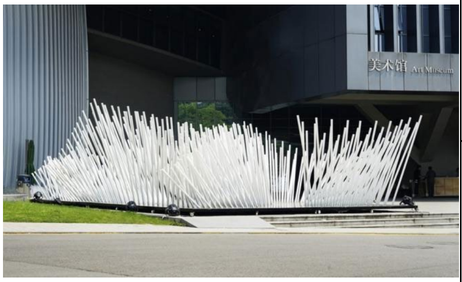
Various examples falling under these categories, such as recreational areas, parks, sports and play areas, tourism and leisure facilities, urban and rural development areas, urban pedestrian areas, and squares, were considered(Yarcı and Malkoç, 2011).

Table 2. Landscape design service type of the study samples.

Study Samples	Type of Design Service	Category	İmages	Year and Location
Curvilign Bench	Object Design	Structural design - Reinforcement design		2015 Uncertain
LightPRO Shell Pavilion	Object Design	Structural design - Landscape Structure		2021 Germany
Urbach Tower	Object Design, Technical Design	Structural design - Landscape Structure		2019 Germany
Please Be Seated	Object Design	Structural design - Reinforcement design		2019 London/ UK
Stadel Museum	Object Design, Technical Design	Structural design - Ceiling design, Landscape design, Natural illumination		2012 Germany

LightWall House	Object Design, Technical Design	Structural design - Wall design, Natural illumination		2012 Turin/ Italy
Bench Layout	Space Design	Bench Layout		Uncertain Finland
Roche Campus Kaiseraugst	Object Design, Space Design, Technical Design	Structural design - Pavement design Planting design, Natural irrigation		2018 Switzerland
Parametric Space Installation	Object Design, Technical Design	Structural design - Reinforceme nt Design		2016 Nanjing/ China
Children's Playground	Object Design, Space Design	Structural design - Playground Design		2020 Guangzho/ China

The South Park	Space Design	Scenario creation		2017 San Francisco/ USA
Keio University	Space Design, Technical Design	Scenario creation, Planting design, Pavement design		2012 Tokyo/ Japan
Sony Forest	Space Design, Planting design	Scenario creation, Planting design		2012 Tokyo/ Japan
Edaphic Effects	Technical Design	Edaphic effects, Irrigation system		2011 Philadelphia /USA
MAX IV Laboratory Landscape	Space Design, Technical Design	Scenario creation, Surface flow management		2016 Lund/ Sweden

(**Note:** The images in this table are taken from sources Anonymous, 2015; Pintos, 2022; ICD/ITKE, 2019; Paul Cocksedge Studio, 2021; Gooood, 2014; EcoLogic Studio, 2012; Anonymous, 2023; Bryum, 2019; Gooood, 2016; L&A Design, 2020; Fletch Studio, 2017; MDP, 2012; Groundhog, 2012; Groundhog, 2011; Groundhog, 2016.)

According to current design examples, parametric design encompasses object design services such as bank design, pavilion design, tower design, seating group design, ceiling window design, wall design, flooring design, and installation design. Technical design services include natural lighting, bench placement, landscaping, natural irrigation, and surface flow management techniques. In spatial design, it covers the creation of green open spaces, scenario development, and playground design.

2.2. Method

Before evaluating landscape design examples in the context of parametric design principles, it is essential to examine the relationships between landscape design principles and parametric design principles. Landscape design principles encompass concepts such as harmony, contrast, dominance, balance, emphasis, focus, rhythm, repetition, hierarchy, and unity. Parametric design principles include assumptions, reductions, and sometimes, these principles overlap with landscape design principles.

The fundamental design elements in landscape architecture include color, texture, scale, form, and line. The use of these elements in the examined examples is analyzed, marking the elements incorporated with a "√" and those not considered with a "-" sign.

Key elements in the formation process of parametric design, such as initial conditions and parameters (inputs), generative mechanisms (rules, algorithms), and conditional control variables (output, product), were considered in the study. These elements were treated as a cyclic process, and the first three stages were analyzed accordingly.

The study explores the relationship between problem-solving and form-logic in landscape design. It emphasizes that form and logic are integral to the design process, where the problem defines the starting point. The study evaluates how these elements influence each other during the design process.

The study also assesses the file formats supported by each CAM tool since this is crucial for ensuring the compatibility of design files. The usability of CAM tools is a significant factor in the design process. A user-friendly interface ensures that the tools are easy to use, contributing to the efficiency of designers during the design process.

The study examines whether the parametric modeling program used is Rhino and Grasshopper. If the program used is not specified, the study assesses whether similar processes can be carried out using Rhino and Grasshopper.

The purpose of comparing computer-aided modeling (CAM) tools is to understand how different tools meet diverse design needs and to evaluate and select the best option. CAM tools are commonly used to expedite the design process, reduce costs, and facilitate the accurate and efficient production of designs. The selected CAM tools for comparison are

AutoCAD, SketchUp, and Rhino. The comparison includes three key aspects These are features and capabilities, supported file formats and ease of use. First section evaluates the different features and capabilities offered by each CAM tool, including aspects such as view area, display mode, rendering capabilities (material, shading, lighting), layers, basic settings, geometry tools, editing tools, layout, and development.

3. Results and Discussion

The discussion will cover the type of landscape design service, the utilization of fundamental design elements, principles of parametric design, and design stages. Additionally, the examples' problems and solutions, design form, creation logic, and the computer-aided modeling tools used in the design process will be addressed. The features of commonly used tools in landscape architecture, namely AutoCAD, SketchUp, and Rhinoceros, will be examined to select a more suitable tool for parametric design.

3.1. Compliance of Study Samples with Landscape Basic Design Elements and Parametric Design Principles

The use of landscape basic design elements in the study examples is shown in the table below (Table 3). The least used of these is colour and the most used is size.

According to Schumacher (2011), parametrisism is the groundbreaking movement after modernism. Just as each movement has its own characteristics, Schumacher has determined principles that should be followed and avoided in parametrisism. These principles are expected to be taken into consideration in the parametric design of landscape elements. Among the study examples, the bank settlement example and the Sony Forest example draw attention by not complying with any principles.

Table 3. Use of landscape basic design elements in the study samples and compliance of study samples with parametric design principles.

Code	Study Samples	Basic Design Elements					Compliance Parameter Design Pirinciples								
							Dogmas					Taboos			
		Colour	Texture	Size	Form	Line	Interrelation	Differentiation of form	Differentiated repetition	Curvilinearity	Parametric design	Universality	Euclidean forms	Lack of interrelation	Simple repetition
1	**Curvilign Bench**	-	√	√	√	√	√	√	√	√	√	√	√	√	√

2	**LightPRO Shell Pavilion**	-	√	√	√	√	√	√	√	√	√	√	√	√	√
3	**Urbach Tower**	-	√	√	√	√	√	√	√	√	√	√	√	√	√
4	**Please Be Seated**	-	√	√	√	√	√	√	√	√	√	√	√	√	√
5	**Stadel Museum**	-	√	√	√	√	√	√	√	√	√	√	√	√	√
6	**LightWall House**	-	√	√	√	√	√	√	√	-	√	√	-	√	√
7	**Bench Layout**	-	-	√	-	√	-	-	-	-	-	-	-	-	-
8	**Roche Campus Kaiseraugst**	-	√	√	√	√	√	√	√	√	√	√	√	√	√
9	**Parametric Space Installation**	√	√	√	√	√	√	√	√	√	√	√	-	√	√
10	**Children's Playground**	√	√	√	√	√	√	-	√	√	√	√	-	√	-
11	**The South Park**	-	√	√	√	√	√	√	√	√	√	√	√	√	√
12	**Keio University**	-	√	√	√	√	√	√	√	√	√	√	√	√	√
13	**Sony Forest**	√	√	√	-	-	-	-	-	-	-	-	-	-	-
14	**Edaphic Effects**	-	-	√	√	√	√	√	√	√	√	√	-	√	√
15	**MAX IV Laboratory Landscape**	-	√	√	√	√	√	√	√	√	√	√	√	√	√

3.2. Use of the Study Sample in the Parametric Design Process (Table 4)

Table 4. Parametric design utilisation analysis of study samples.

Study Samples	Initial conditions and parameters (Inputs)	Generation mechanism (Rules, Algorithms)	Conditional control variables (Output, Product)
Curvilign Bench	The general form created with curves.	1. Placing points at equal intervals along the curves; 2. Creating surfaces with points and curves.	1. Ensuring the smoothness of curves (linear optimization); 2. Material thickness.
LightPRO Shell Pavilion	The general form created with curves.	1. Placing points at equal intervals along the curves; 2. Creating surfaces with points and curves.	Ensuring the smoothness of curves (linear optimization).
Urbach Tower	Wooden piece.	The appropriate calculation and assembly form.	The maximum slope of the wood, the diameter of the tower.
Please Be Seated	The general form created with curves.	1. Placing points at equal intervals along the curves; 2. Creating surfaces with points and curves.	Ensuring the smoothness of curves (linear optimization).
Stadel Museum	Sunlight.	1. Placing points at equal intervals along the curves; 2. Creating surfaces with points and curves.	Ensuring the smoothness of curves (linear optimization).
LightWall House	Wall Opening Unit.	The appropriate use of the rule.	Light direction.

Bench Layout	The desired number of benches and space limit.	Taking into consideration the principle that both lines passing through seating points in the area are not parallel, randomly distributed seating points and orientations are obtained.	The distribution range of bench placement points.
Roche Campus Kaiseraugst	Pedestrian flow, seating areas, and types of existing plants.	Leaving gaps in ground covering based on plant types and the law of plant growth.	Arrangement of plants of different types, pavement form.
Parametric Space Installation	The number and location of "wheat".	The appropriate use of the rule.	The direction of curvature of the "wheat".
Children's Playground	Boundary line of the area versus.	The appropriate use of the rule.	Form size and slope degrees.
The South Park	The value of data collected from the surroundings.	Multi-stage appropriate rules.	The optimization of road curves.
Keio University	Paver depth, dimensions, plant palette, etc.	The appropriate use of the rule.	An empirical ground covering form.
Sony Forest	The type of plants, etc.	The appropriate use of the rule.	Scattering seed points.
Edaphic Effects	Curves drawn based on the terrain slope.	Calculating surface water flow by finding the highest and shortest points within a unit "diamond".	The dimensions of the unit "diamond".
MAX IV Laboratory Landscape	A series of geometric projections extending tangentially from the outer ring of the laboratory building and intersecting.	Erecting peaks on units formed by intersecting lines.	The dimensions of unit peaks.

3.3. Problem-Solution, Form-Logic Relationships in Parametric Landscape Design

The following conclusions were obtained from the case studies in the relations of problem-solution, form-logic. The form-logic relationship is summarised in two types according to problem-solution differences (Table 5).

Table 5. Analysis of problem-solution, form-logic relationships of study samples.

Study Samples	Problem-Solution	Form-Logic
Curvilign Bench	Creating a parametric furniture design inspired by the depths of the ocean, where form takes shape, and fluidity is synthesized; The form is observed to resemble a whale shark.	Pursuit of modeling logic with the goal of finding form, starting from bionics.
		Seeking logic from form
LightPRO Shell Pavilion	Creating a sustainable architectural example for the future by incorporating the use of alternative sustainable materials and presenting innovative approaches in structural applications.	Pursuit of modeling logic with the goal of finding form.
		Seeking logic from form
Urbach Tower	A tower design incorporating aesthetic and sustainable features.	Pursuit of modeling logic with the goal of finding form.

		Data analysis in a computer environment.
		Seeking logic from form
Please Be Seated	Enriching the atmosphere of the square by bringing together art, functionality, and interaction, enhancing the overall experience of the space.	Pursuit of modeling logic with the goal of finding form.
		Seeking logic from form
Stadel Museum	Enhancing natural light to create an airy and accessible interior, constructing a building in accordance with the principles of environmental sustainability, and promoting cultural interaction. Simultaneously, aiming to strengthen the museum's identity through green roof and garden design.	Finding form through problem-solving logic.
		The search for form from logic.
LightWall House	The aim is to enhance indoor comfort and energy efficiency with a specially designed wall solution, considering sunlight, light, and privacy conditions.	Finding form through problem-solving logic.
		The search for form from logic.
Bench Layout	To prevent discomfort, individuals seeking relaxation in open spaces avoid making eye contact with strangers.	Starting with problem-solving logic and using parametric design tools to find placement points.
		The search for form from logic.
Roche Campus Kaiseraugst	Creating a vital habitat for flora and fauna in this green area, enhancing the ecological sustainability of a large corporate facility, while providing employees and visitors with a clean, green, and appealing environment.	Starting with problem-solving logic and using parametric design tools to find placement points.
		The search for form from logic.
Parametric Space Installation	Utilizing parametric techniques to recreate natural phenomena, providing people with a fun and interactive spatial experience, and drawing attention to the natural environment through digital forms to offer “landscape representation” and “landscape narration”.	Pursuit of modeling logic with the goal of finding form.
		Seeking logic from form
Children's Playground	A multifunctional children's play area that combines entertainment and education.	Pursuit of modeling logic with the goal of finding form.
		Seeking logic from form
The South Park	Creating an efficient space by parameterizing data collected from the environment.	Finding form through problem-solving logic.
		The search for form from logic.
Keio University	The request for a tightly bounded and highly sculpted rooftop garden aims to create a space showcasing rich diversity and dynamism, characteristic of a traditional Japanese garden.	Finding form through problem-solving logic.
		The search for form from logic.
Sony Forest	Scattering seeds with consideration for the laws of plant growth.	Finding form through problem-solving logic.
		The search for form from logic.
Edaphic Effects	Generating infiltration infrastructure on-site with parametric models. This project aimed to demonstrate the potential of "incremental	Finding form through problem-solving logic.

<table>
<tr><td></td><td>infrastructures" to improve Philadelphia's stormwater infrastructure. To achieve this, a dispersed geotextile network has been proposed as a means of increasing water retention in vacant lands.</td><td>The search for form from logic.</td></tr>
<tr><td rowspan="2">MAX IV Laboratory Landscape</td><td rowspan="2">The measurements taken from sensitive laboratory instruments were affected by external vibrations originating from the nearby highway. The flat topography of the area allowed surface vibrations to move freely. Therefore, one of the fundamental objectives of the design was to maximize the surface area of the landscape through undulating topography, which would better distribute vibrations that could impede the laboratory's operation. Additionally, some ancillary benefits, such as managing surface runoff, can also be achieved through such topography.</td><td>Finding form through problem-solving logic.</td></tr>
<tr><td>The search for form from logic.</td></tr>
</table>

3.4. Use of Computer Aided Modelling Tools in Study Samples

Table 6. Use of computer aided modelling tools in study samples.

Study Samples	Used Programs	Available Programs
Curvilign Bench	Rhino & Grasshopper	
LightPRO Shell Pavilion	Uncertain	Rhino & Grasshopper
Urbach Tower	Uncertain	Rhino & Grasshopper
Please Be Seated	Uncertain	Rhino & Grasshopper
Stadel Museum	Uncertain	Rhino & Grasshopper
LightWall House	Bentley Generative Components	Rhino & Grasshopper
Bench Layout	Uncertain	Rhino & Grasshopper
Roche Campus Kaiseraugst	Uncertain	Rhino & Grasshopper
Parametric Space Installation	Rhino & Grasshopper	
Children's Playground	Uncertain	Rhino & Grasshopper
The South Park	Rhino & Grasshopper	
Keio University	Rhino & Grasshopper	
Sony Forest	Rhino & Grasshopper	
Edaphic Effects	Rhino & Grasshopper	
MAX IV Laboratory Landscape	Rhino & Grasshopper	

The result of the comparison of computer aided modelling tools in parametric design, as reflected in table 6 and table 7, shows that the Rhino programme is more advantageous in most features (Table 6 and Table 7). The multi-command nature of the viewport means that the navigation movement towards the inspection of the model is more independent and multi-directional. The multi-command display mode diversified the visual appearance of the model. It is seen that Rhino programme has more advantages than other programmes in rendering. The fact that the rendering command has various and multiple settings contributes to the model visuals to be more realistic. It is seen that the layers and basic settings are at an intermediate level. It is seen to be very advantageous in supported file formats and geometry settings. In the development programmes, the contribution of grasshopper software has made Rhino programme the biggest advantage.

Table 7. Comparison of modelling tools.

		AutoCAD	Sketch Up	Rhino&Grasshopper
views		Few commands	Mid-number command	Multi command
Display Mode		Few commands	Mid-number command	Multi command
Render	**Material**	non-existent	existence	existence
	Shadowing	non-existent	existence	existence
	Light	non-existent	non-existent	existence
	Render	non-existent	Render added	Own rendering available; Render added
Layers		Multi command	Few commands	Mid-number command
Basic Interfaces		existence	existence	existence
Geometry	**Contrution planes+Vector**	non-existent	non-existent	existence
	Creation settings	Few commands	Mid-number command	Multi command
	Edit settings	Mid-number command	Mid-number command	Multi command
	Attributes	Detailed	Less detailed	Medium detailed
	Select	Varied settings	Simple setting	Diverse Command
	Group	existence	existence	existence
	measure	Mid-number command	Few commands	Multi command
	Object Snap	existence	non-existent	existence
	Layout	existence	non-existent	existence
Development Programmes		Few varieties	non-existent	Wide variety
File Formats Supported		few	middle	a lot

4. Results

4.1. The Use of Parametric Design in Landscape Architecture

In the landscape design process, the analysis stage and the design stage are generally iterative. The transition to the modification and improvement stage occurs based on the user's (client) feedback during evaluation. In traditional design, these processes are subject to longer time costs, but in parametric design, obtaining various results has become an instantaneous operation, as reflected in Table 8 (Table 8). Parametric design is not universally applicable at every stage of the landscape design process, despite the advantages offered by computer-aided design; efforts from designers or users are still necessary. As expressed by Fletcher (2018; cited in Groundhog), 'Memory, experience, emotion, and humor are parameters that cannot yet be placed within a parametric definition.'

Designers may encounter limitations in determining every desired piece of information in the parametric modeling process, and similarly, users may not be able to fully express aesthetic values and emotional responses through computer algorithms.

Landscape elements can be designed in various ways using the parametric design method. For instance, details such as plant selections, garden designs, seating areas, outdoor activities, and landscape features can be designed using parametric models and algorithms.

One of the significant advantages of parametric design is its provision of flexibility and speed in the design process. Parameters and variables allow for the rapid exploration and optimization of different scenarios in the design. Additionally, this design method can contribute to better design quality, increased innovation and diversity, and improved functionality.

The use of parametric design for landscape elements can make the design process more efficient, effective, and creative. Furthermore, the outcomes of parametric design can assist in producing more sustainable, environmentally friendly, and innovative designs in the landscape field. The application of parametric design to landscape elements enhances the aesthetic value of the design.

Table 8. Parameterization possibilities in the landscape design process.

Design Process	Work Stages	Criteria Leading to the Result	Result
Research and Analysis Phase	Defining the Problem	The user's expectations from the design of the space or the negative effects that are desired to be eliminated.	Non-parameterizable
	Determination of Existing Conditions	Determination of existing conditions, determination of user requirements, collection of general information.	Parameterizable
	Field Analysis	Determination of design parameters and rules by the designer.	Parameterizable
Design Phase	Event List		
	Synthesis	Creation of the design model by the designer using modeling tools.	Parameterizable
	Create a scenario	The first model created by the designer.	Parameterizable
	Creating Design Options	Producing multiple options by diversifying the scenarios created by the designer according to different elements.	Parameterizable

	Evaluating Options	Quantitative evaluation of the created model.	Parameterizable
		Evaluation of aesthetics and abstract.	Non-parameterizable
	Choosing a Product	Choosing the most suitable product according to the result of the assessment.	Parameterizable
Development Phase	Structural Design	Continue the object design service on the script.	Parameterizable
	Planting Design	To continue the planting service on the scenario.	Parameterizable
	Detail Design	Elaboration of the final design obtained, development of the irrigation system and lighting system.	Parameterizable
Application		Landscape construction.	-

4.2. Computer-Aided Design Tools in Parametric Landscape Design

Computer-aided modeling tools play a crucial role in the advancement of parametric landscape design. Parametric design is an approach where parameters and relationships are expressed through mathematical or algorithmic models during the design process. Computer-aided modeling tools are essential in facilitating this process and offer several advantages that enhance both the design and its outcomes.

One of the primary benefits of parametric modeling is its ability to enable rapid iteration and adaptation. By adjusting various parameters, designers can quickly explore and evaluate different design alternatives, which results in a more efficient design process. This flexibility not only accelerates decision-making but also fosters a deeper understanding of the relationships between different elements within the design.

Parametric modeling is also crucial for managing complexity in landscape design. Landscapes often consist of intricate relationships between environmental, structural, and aesthetic components. By utilizing parametric tools, these complex relationships can be broken down into manageable, understandable parts. This allows designers to navigate and manipulate the design more effectively, ensuring that all elements work harmoniously.

Moreover, computer-aided parametric tools enhance the analysis of environmental impacts. In landscape design, environmental factors such as sunlight, wind direction, and topography play a significant role in determining the success and sustainability of a project. Parametric models allow for detailed analysis and optimization of these factors, enabling designs that are more environmentally sensitive and perform better under various conditions.

Data-driven decision-making is another advantage provided by parametric modeling. By integrating data from sources such as geographic information systems (GIS) and other measurements, designers can base their decisions on quantitative data. This approach ensures that the design is grounded in measurable parameters, leading to more accurate and informed design choices.

In addition to functional benefits, parametric modeling tools also contribute to the aesthetic and visualization aspects of landscape design. The ability to create complex forms and patterns with ease enhances the aesthetic richness of a design. Furthermore, 3D visualizations and animations generated through these tools provide designers and stakeholders with a clearer understanding of the final product, improving communication and decision-making.

Optimization is another critical role of parametric modeling in landscape design. By applying optimization techniques, designers can ensure that the design meets specific performance goals, such as water management, energy efficiency, or ecological sustainability. The use of parametric tools makes it easier to test various scenarios and optimize design parameters accordingly.

Finally, collaboration and communication within design teams are greatly enhanced through parametric modeling tools. Virtual environments enable designers to share and understand different aspects of the design in real time, facilitating more effective teamwork and clearer communication of design ideas.

In conclusion, computer-aided modeling tools play a pivotal role in the advancement of parametric landscape design. These tools contribute to more efficient, complex, data-driven, and environmentally sensitive designs while improving collaboration and optimization efforts. As parametric landscape design continues to evolve, the use of these tools will remain essential for pushing the boundaries of creativity and functionality in the field.

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