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PARAMETRIC DESIGN FOR AN OUTDOOR BENCH

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Abstract: *This paper describes the parametric design process of a piece of furniture, examining its positive and negative experiences. The research has focused on the concept of parametric design, its initial endeavors and the contemporary experiments of renowned designers. Information gathering played a crucial role in compiling the requirements concerning functionality, load capacity, size, design and style. Our aim was to create a modular communal outdoor bench that can be varied according to needs, establishing a connection between the space and its users, and bearing special aesthetic value both in its form and surface design. An important consideration was that the experimental furniture should be made from environmentally friendly and biodegradable materials.*
The parametric form required a surface texture different from the traditional, thus elements of Penrose tiling were placed at the center of the design, which connects to parametricism in a special way both mathematically and in terms of design history. The Penrose patterns defined the character of the furniture.
The article also shows the visual designs and a 3D printed mock-up. The further development of this bench primarily lies in software development, enabling the generation of new patterns.

Keywords: *Parmetric design, Communal outdoor bench, Penrose pattern*

1. INTRODUCTION

Parametric design seeks the ideal form that is functional, ergonomic, and harmoniously integrates with nature. Natural forms such as eggshells, leaf veins, seashells, wasp nests, corals, and spider webs exemplify structures with maximal load-bearing capacity, minimal material usage, and environmental friendliness, making them suitable to be considered parametric forms.

The fundamental elements of parametric design include data collection, drawing, modification, form exploration, module creation, mathematical modeling, and pattern recognition, all of which must be integrated throughout the design process. Before the advent of computer technology, achieving this required a deep understanding and application of complex mathematical relationships [1]. With computer-aided design, algorithms can generate innovative and unexpected forms based on defined parameters. These forms may appear highly futuristic but can also encompass traditional shapes, such as saddle surfaces, sine curves, or natural structures like stalactite caves [2].

The concept, as defined by Patrik Schumacher [3], positions parametricism as the leading architectural style of the 21st century, addressing technological advancements and the challenges posed by the information society [4]. He proposes a novel coding system enabled by computers and non-Euclidean geometry, capable of generating parametric systems that shape the geometry of buildings and objects. This approach departs from the traditional framework of parallels and perpendiculars, instead adapting to the dynamic needs of a contemporary society. By utilizing coding, it establishes a complex order where every design element and system interrelate and mutually define one another [5].

Engineering design and industrial design can be perceived as a series of decisions that, in the case of parametric design, can be broken down into four fundamental tasks:

- Establishing the key parameters that decisively influence the design process.
- Assessing the relationships between these parameters.
- Modifying the design process based on the expected outcomes.
- Continuously evaluating partial results while keeping the ultimate goal in focus [6].

In the early stages of parametric design, creating complex structures involved a series of complicated calculations (Figure 1.).

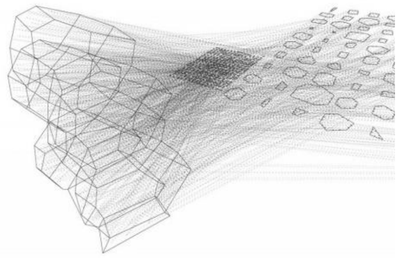

Figure 1. Parametric design [7].

The initial labor-intensive phase pays off when we can customize the manufacturing process for mass production by changing only one or two parameters to create unique items instead of mass-produced goods. However, good and well-thought-out designs cannot be produced at the push of a button [8]. A long learning process is required even with different software programs, but they are essential for competitive design. These programs include AutoCAD, Autodesk Inventor, Blender, Rhinoceros 3D, Grasshopper, Maya, SketchUp, Generative Components, and Houdini [7].

The applications of parametric design are expanding daily. While its development is primarily linked to architecture, it is also utilized in landscape architecture, automotive manufacturing, interior design solutions, and various aspects of the designed environment, including furniture, fixtures, and fashion design [9].

2. PRECEDENCES FROM THE BEGINNING TO DATE

When researching the origins of parametric design and parametric architecture, we can approach the topic from several historical perspectives. Antoni Gaudí, Friedrich Kiesler, Frei Otto, and Eero Saarinen are regarded as forefathers of parametric architecture. According to many sources, Italian architect Luigi Moretti (1907–1973) was the first to use the term parametric architecture in the 1940s [3]. He argued that architects should study architecture as a system, focusing on dimensions and architectural elements that depend on parameters. These parameters serve as the initial data for the design task, such as function, purpose, and location. Moretti demonstrated this approach through the design of a stadium, which, he argued, depended on nineteen parameters. These included cost factors for concrete production, the steepness of the stands, the number of spectators, and the viewing angle. The plans for the parametric stadium were presented in 1960 at the 12th Milan Triennial in the exhibition titled "Parametric Architecture" (Figure 2.).

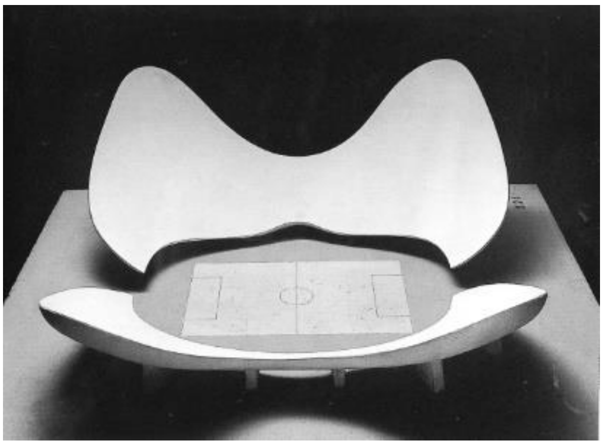

Figure 2. Luigi Moretti: Football stadium model, 1960 [3].

Frank Gehry, an American architect born in 1929 in Canada, studied at the University of Southern California and Harvard before beginning his career in Los Angeles. His entire body of work reflects a creative reimagining of building and object design. As a master of parametric design, he defies conventions, creating buildings that are astonishingly diverse and exhibit an incredibly rich formal vocabulary. Some of his best-known works include the Walt Disney Concert Hall in Los Angeles (1988-2003) (Figure 3.), Neuer Zollhof in Düsseldorf (1999), Vitra Design Museum in Weil am Rhein (1989), Gehry House in Santa Monica (1978), and the Olympic Fish Pavilion in Barcelona (1992) [11] (Figure 4.).

Figure 3. Walt Disney Concert Hall, Los Angeles [11].

Figure 4. Olympic Fish Pavilion, Barcelona, Spain[11].

There has been a significant transformation in the built environment over the last few decades, led by Hungarian architects. Iconic buildings have been constructed using parametric design principles.

The modernization and quality expansion of Jedlik High School (Figures 5. and 6.) were guided by the principles of parametricism and ecological thinking. This project was carried out by architects Ádám Szabó, Zoltán Porcsalmy, Zoltán Reznicsek, Levente Gyulai, and Anett Mizsei [12].

Figure 5. Inside of the Jedlik High School [12].

Figure 6. South wing of the Jedlik High School [12].

The Hungexpo F1 Reception Building (Figures 7. and 8.) was designed by Finta Studio, with architects Péter Dóczé DLA and Mária Magyar DLA. The building is beautifully situated, taking into account the clusters of trees and the existing pathways in the area. The architecture is characterized by a geometry resembling a triskelion silhouette, an ancient symbol of eternity [13].

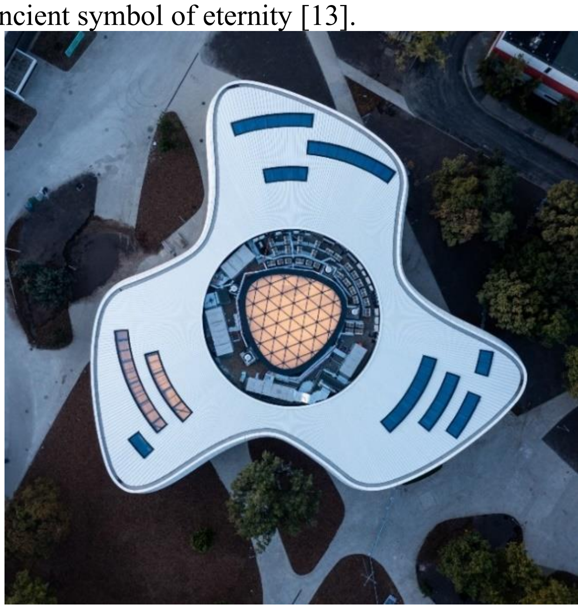

Figure 7. Top view of Hungexpo F1 Reception Building [13].

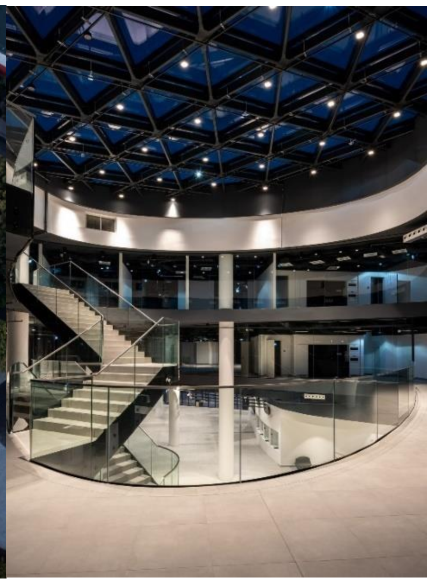

Figure 8. Interior of Hungexpo F1 Reception Building [13].

The third parametric design we must mention, called Biodome (Figure 9.), designed by Mérték Architectural Studio Ltd., (Paulinyi & Partners) and ABUD Engineering Ltd. It was intended to function as a covered zoo. The distinctive feature of the building is its large span roof, made of steel and a special foil. The architectural concept aimed to accommodate various ecosystems. The double-curved roof acts as an intelligent skin, capable of responding to weather changes, to provide interior comfort [14]. The Biodome won the International Property Awards in 2018.

Figure 9.Biodome [14].

Zaha Hadid (1950–2016), the Iraqi-British architect and designer, left an indelible mark on the history of architecture. Her parametric structures have become iconic landmarks in major cities, while her product designs — including furniture (Figure 10.), lighting fixtures, shoes, and jewelry — have achieved worldwide acclaim [15].

Figure 10. Zaha Hadid: UltraStellar furniture collection. [https://www.dezeen.com/2016/10/03/ultrastellar-zaha-hadid-architects-patrik-schumacher-wood-leather-furniture-design/]

Kas Oosterhuis, a Dutch architect and designer, is a member of Parametricism as a Platform for 21st Century Architecture and Design. He is known for designing iconic buildings, such as the Bálna in Budapest. In his architectural work, he emphasizes a new functionality by creating spaces that adapt to changing functions over time, incorporating furniture that can be folded out and retracted.

If parametric design enables such flexible possibilities, buildings and objects can exist in a state of continuous motion and transformation. Oosterhuis envisions the future of design as interactive, where every object can take on a personalized form, becoming a unique piece. His Body Chair (Figure 11.), a parametric chair, exemplifies this concept: it can be customized during production based on the customer's body measurements, making each piece unique and tailored for maximum comfort.

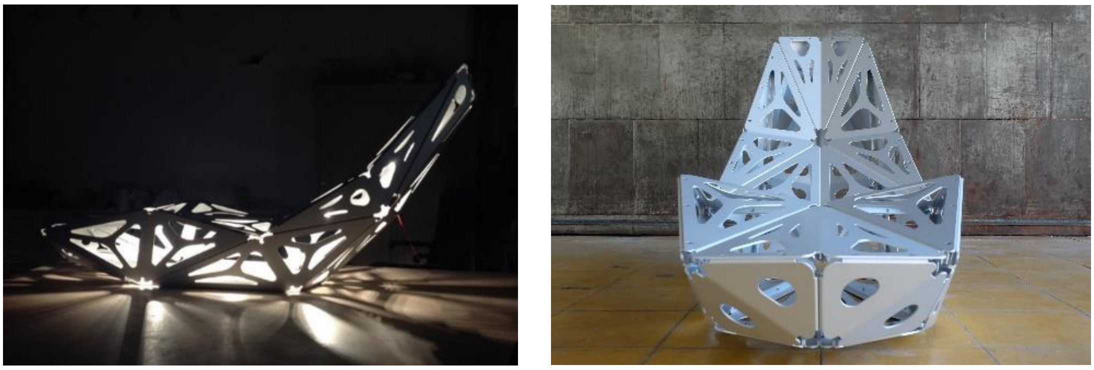

Figure 11. Kas Oosterhuis: Body Chair [16].

Martin Oberhauser, a South Tyrolean architect-designer, created the No One Chair, a 3D-printed, recyclable, outdoor eco-furniture piece that is an exceptionally successful example of parametric design (Figure 12.). Made from a material combining concrete and glass waste, it is weather-resistant while showcasing a light and organic form inspired by biological structures. Prior to this, Oberhauser designed a similar lighting fixture as the first application of his innovative concrete printing technology. With the No One Chair, he won a Red Dot Award in 2022.

Figure 12. Oberhauser: Nº One Chair [Studio Oberhauser homepage] [17].

3. THE PENROSE TILING

The seamless covering of planes with various polygons is known as the tiling or tessellation problem, which traces its origins back to the 1600s and the work of *Johannes Kepler*, a German mathematician and astronomer. In the 1970s, it was discovered that there are six types of polygons capable of creating endless patterns (Figure 13.).

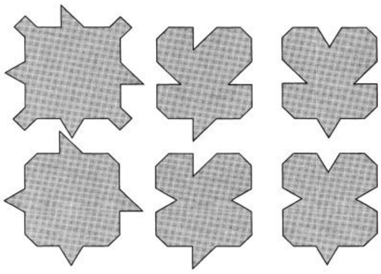

Figure 13. The first six aperiodic tiles [18].

Building on this, Roger Penrose (1931–), an English mathematician and theoretical physicist, introduced a two-piece solution: one consisting of two rhombi, and another involving a convex and a concave deltoid (Figure 14.).

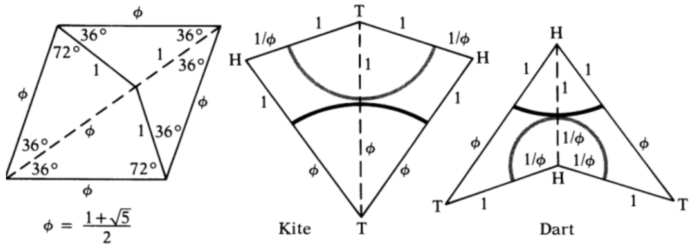

Figure 14. „Kite” and „Dart” Penrose tiles [18].

From then on, more and more two-tile and three-tile methods were discovered. However, until this year, it remained a mystery whether a single tile could cover a plane infinitely without symmetry or repetition. In 2023, a printing technician named David Smith discovered a shape that allows for infinite, non-repeating, asymmetric coverings [16]. The shape, humorously named "the hat," became a global sensation (Figure 15.).

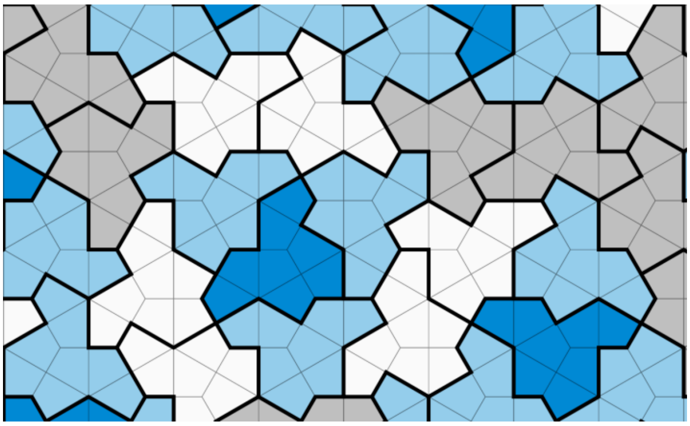

Figure 15. The „hat” [20].

Originally, this was intended to be the pattern for the planned seating furniture, although newer shapes have since been discovered. In response to criticisms that the hat shape could only tile the plane by using its mirror image, David Smith, in June, created a shape that can tile the plane entirely on its own, without reflection [19] (Figure 16.).

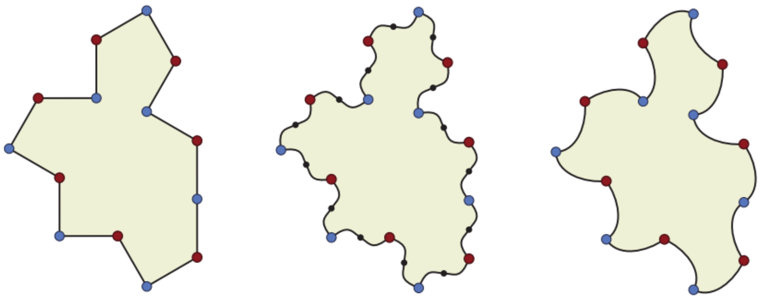

Figure 16. The „spectre” [20]

4. THE DESIGN METHOD

In designing the seating furniture, it was crucial to ensure that, beyond functionality, it also conveyed aesthetic value and could be utilized in both outdoor and indoor communal spaces. The modular design promotes connections among users. The curvature of the benches allows individuals to transition from social distance to personal distance, accommodating both intimate closeness and separation. Additionally, the surface was required to be easy to clean and disinfect.

After gathering information, the initial step in the design process was to determine the optimal seat height, backrest height, and seat depth. These dimensions were based on data collected from seating furniture deemed comfortable by test subjects (Table 1.).

Test subject	Seat height[cm]	Seat depth[cm]	Support height[cm]
1	48	50	50
2	44	43	45
3	45	50	40
4	38	45	48
5	40	60	50
6	45	50	40
7	44	43	50
8	38	45	48
9	48	50	50
10	45	40	40
11	40	60	50
12	38	45	48
13	40	60	50
14	38	45	48
15	40	60	50
Summary	**42**	**50**	**48**

Table 1.

Using the defined data, the sectional drawing of the seating furniture was dimensioned. The transformation of these shapes into seating benches was achieved using the Grasshopper program. In the first design, the future furniture was arranged along a semicircular arc. In the second design, it was aligned along a straight line, with the seating direction reversed along the length of the bench, creating two separate seating areas. The third design, also semicircular, features a gradient that allows for two seating directions on the same bench. To ensure modularity, the resulting shapes were divided into smaller units.

4. FORM VARIATIONS

4.1 The first design is a semicircular seating structure composed of four modules. The backrest is positioned on the outer side. Each element is approximately one meter long, representing an eighth of a circle. These modules can be arranged in various configurations to suit the size and nature of the space as well as the intended use (Figure 17.).

Figure 17. First version top view and perspective image.

4.2 The second design features a straight bench with a backrest that gradually shifts the seating direction. Further development of this design was not considered practical, as the spatial-forming characteristics of a straight line are unsuitable from both an environmental psychology and aesthetic perspective (Figure 18.).

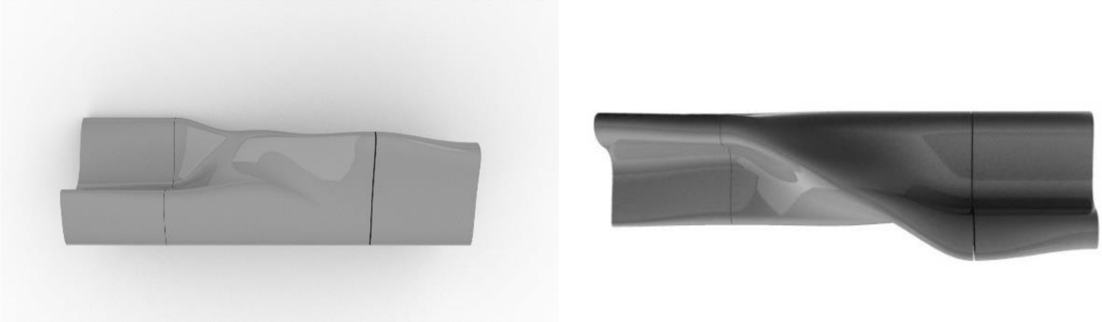

Figure 18. The second version in front and top view.

4.3 In the third version, a bench was designed by combining elements of the two previous designs into a semicircular arrangement of four parts, with a gradual shift in seating direction. The modular components can be arranged as desired, forming configurations where they either face each other or turn away from each other. These modules can be grouped into various convex and concave shapes, making this design suitable for detailed development (Figure 19.).

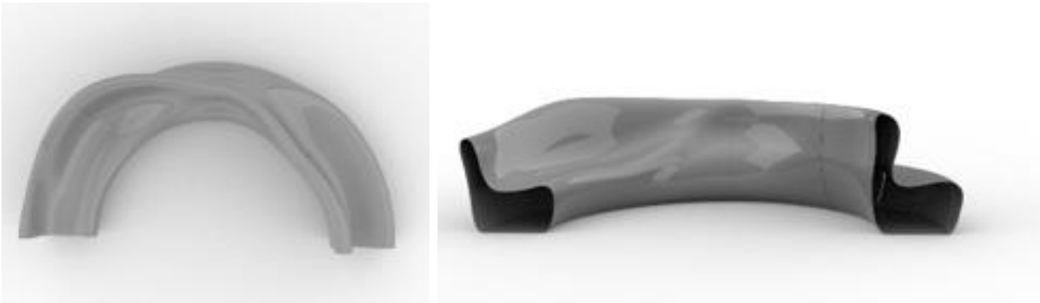

Figure 19. The third version of the bench with backrest.

After defining the basic shapes, the design intended for modeling and prototype production was created using the Rhinoceros 3D and Grasshopper programs. An outer and inner frame serves to delineate the changing contour. Within the frames, the surface was created by establishing five different sectional contours (Figure 20.) in pairs, which form the seat surface of the bench.

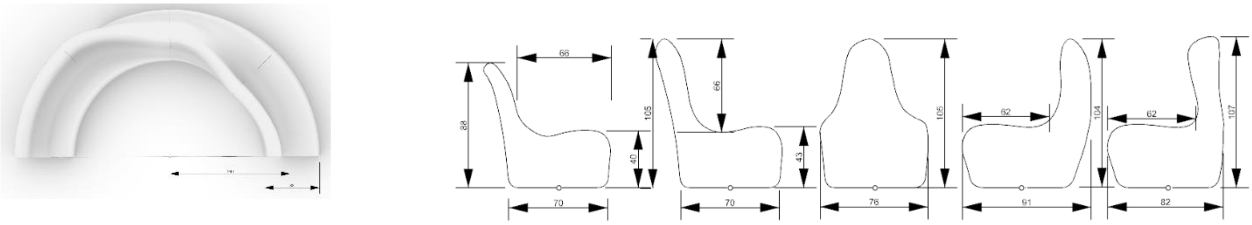

Figure 20. Dimensions and sizing of the seating furniture.

The outer radius of the arc measures 2.2 meters, while the inner radius is 1.4 meters. On one side of the bench, the seating surface faces inward, whereas on the other side, it faces outward. Each module is designed to accommodate one or two people, allowing the sofa to hold a maximum of six individuals. Alternatively, the modules can be arranged to seat up to eight people.
This homogeneous surface provided an excellent foundation for incorporating a unique, perforated pattern based on the Penrose tile design. Initially, the new "single-tile" Hat pattern was selected. However, when the pattern was input into the program and projected onto the furniture's surface, the software interpreted it as individual arcs due to the pattern's complexity. This unpredictability resulted in either a "memory overflow" error message or a complete program crash.

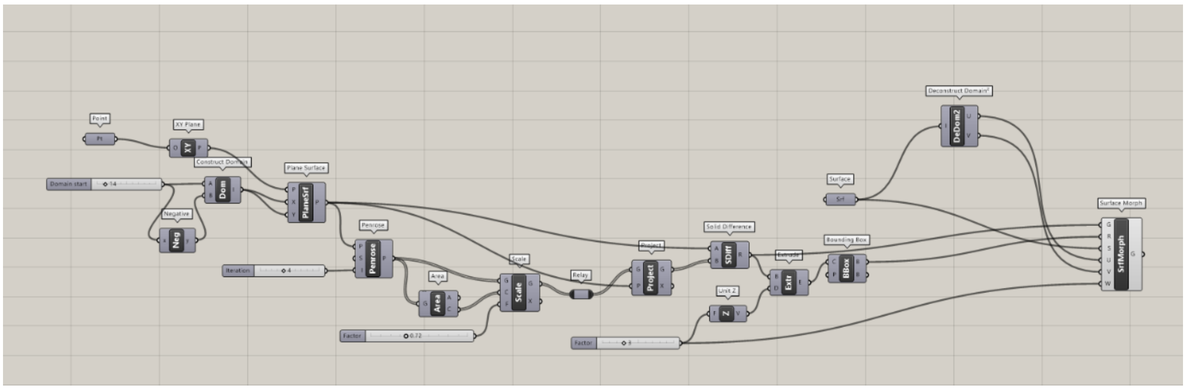

Figure 21. The Grashopper diagram.

After upgrading to a larger 32 GB memory, the program performed better, but it could still only handle smaller sections. Experimentation took a lot of time. The program struggled with the non-repeating pattern and couldn't generate a grid structure to fit the pattern. Replacing the relatively old Rhinoceros version 6 with version 8, which includes the ability to generate the Penrose two-tile pattern, seemed like a good solution. However, even after installing the new version, the pattern could not be applied. As a result, a grid based on the original two-rhombus Penrose tiling pattern was created, which the program was able to handle (Figure 22.).

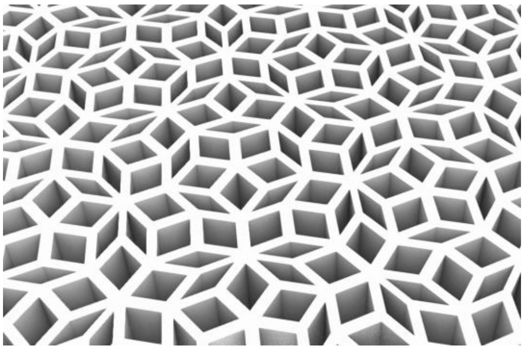

Figure 22. The rhomboids of Penrose pattern.

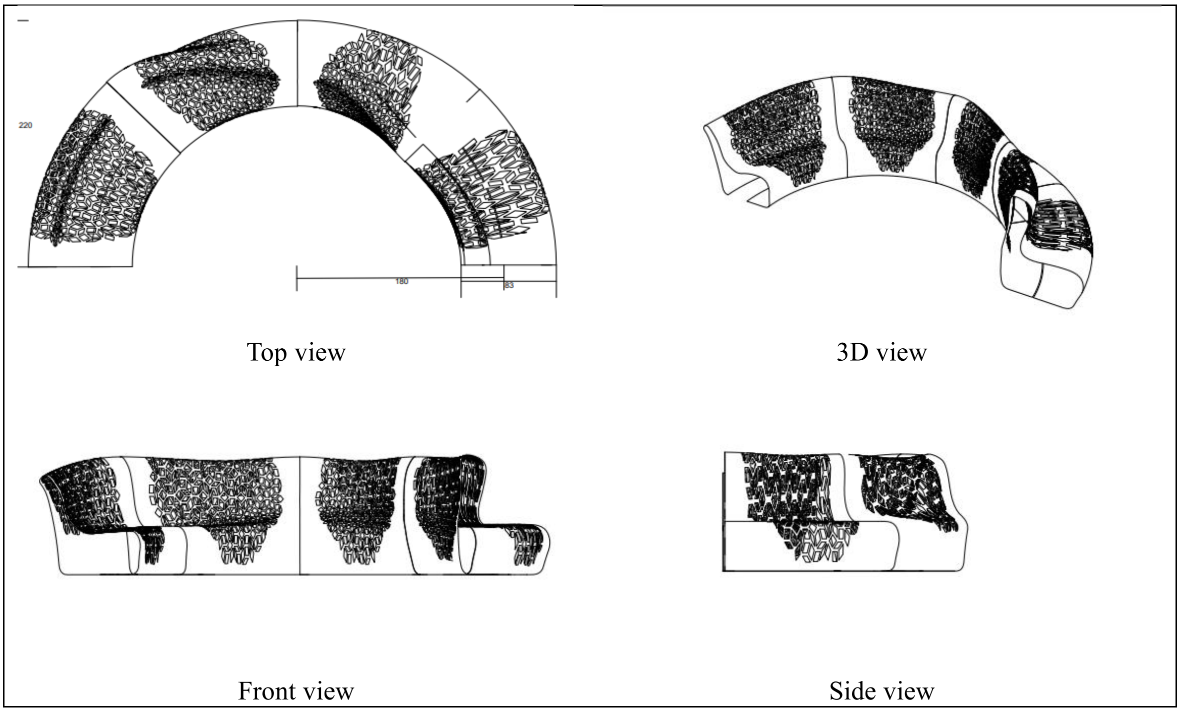

Figure 23. Technical drawing.

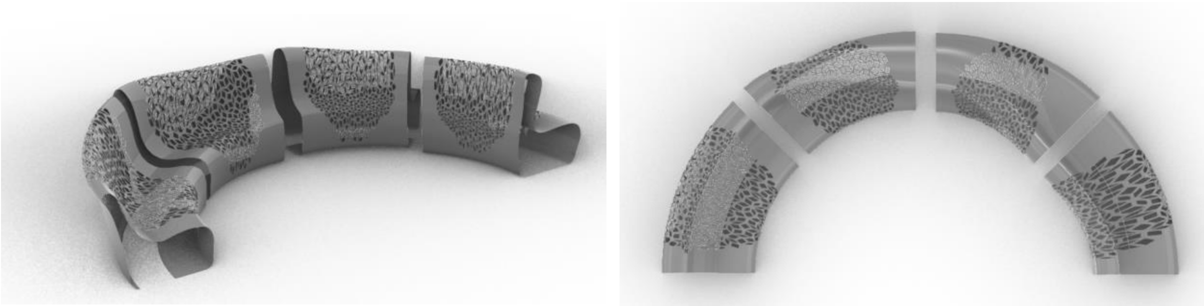

Figure 24. The state of the Penrose pattern mesh created.

Based on the designs, a 1:15 scale model was produced using 3D printing, clearly showing the structure of the bench, its pattern, and the possible spatial arrangements.

Figure 25. 3D printed model with two and four modules (1:15).

Regarding the material, we selected the 'Extrudr Green-TEC PRO Carbon' 3D printing filament for its superior static properties. Reinforced with carbon fibers, this material can withstand significantly higher stress than typical loads. According to the technical specifications, its breaking stress of 58 megapascals (MPa) and tensile strength of 65 megapascals (MPa) enable it to endure multiple times the normal workload [21].
The visualizations showcase, on one hand, the color variations of the final product tailored to different needs, and on the other hand, its placement in a fictional setting. The gray color, with its neutrality, blends seamlessly into any environment. The green variations emphasize a connection to nature, while the purplish-pink option is intentionally striking, designed to stand out in a homogeneous setting.

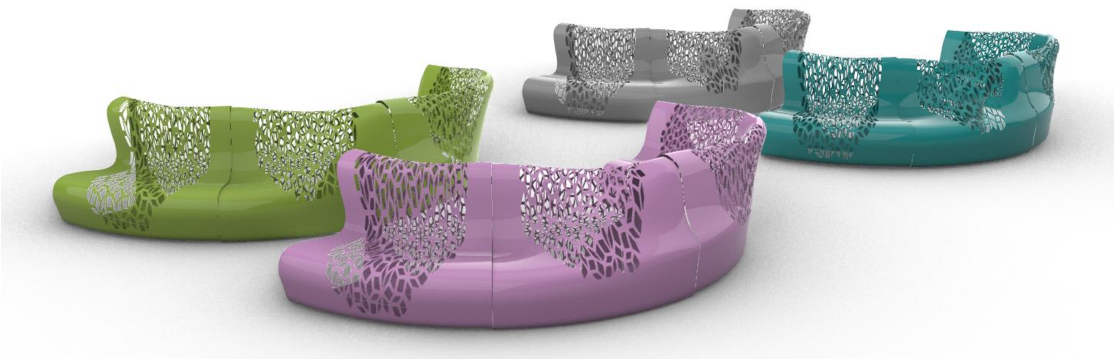

Figure 26. Color variations of the final product shown in top view and perspective.

Figure 27. Visual design for outdoor placement.

Considering the available spaces, the four-module bench system can be further combined in any direction (Figure 28.).

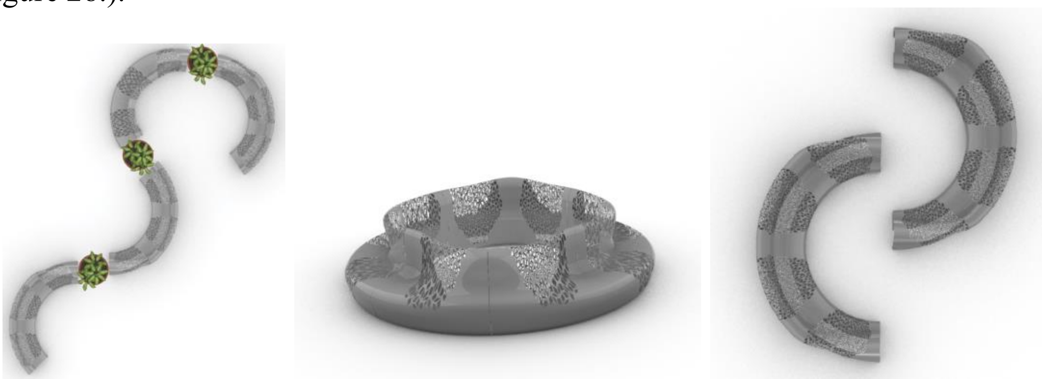

Figure 28. Top view of the seating furniture that can be combined in different ways.

CONCLUSION

The article's relevance lies in the innovative integration of parametric design, 3D printing, and the Penrose pattern. Utilizing 3D software not only streamlines the manufacturing process but also enables the customization of products to better address customers' unique requirements through advanced shaping techniques. The bench is crafted from an environmentally friendly material that is recyclable and biodegradable.

The design process included the presentation of three experimental furniture concepts, culminating in a detailed analysis of the chosen piece. This analysis covered placement variations, surface treatment options, and material selection.

Currently, only a 3D-printed 1:15 scale model has been created due to the high production cost of a full-scale prototype. If manufactured, the design would require load testing, and upon obtaining positive results, the seating furniture could proceed to production.

To enhance user comfort, the outdoor bench incorporates options for charging smart devices (via USB or wireless technology) and internet connectivity. While its organic form does not permit the installation of large solar panels, various renewable, solar-powered functionalities could still be integrated. By experimenting with and designing a new spatial element, these features could be further developed, though this exploration forms part of a separate research project.

REFERENCES

[1] **Woodbury, R.,** (2010): Elements of Parametric Design, Routledge USA, New York, 2010.

[2] **Kolba M.,** (2023): Parametrikus építészet – az igazi természeti-zöld építészet lehetősége 2023. február 28. https://kolba.hu/?project=parametrikus-epiteszet-az-igazi-termeszeti-zold-epiteszet-lehetosege

[3] **Botzheim, B.,** (2015): Az építészet határterületei, Hungarian Arhitecture/Magyar Építőművészet, 2015/4. https://meonline.hu/archivum/az-epiteszet-hatarteruletei/

[4] **Schumacher, P.,** (2009): Parametricism: A New Global Style for Architecture and Urban Design, in *Architectural Design, 2009.*

[5] **Botzheim B.,** (2008): Parametrikus építészet –kódra fel! Magyar Építőművészet/Hungarian Architecture, 2008/01. https://meonline.hu/vizualis-kultura/parametrikus-epiteszet/

[6] **Marcus, A.,** (2013): Positioning Parametric Design: Interfacing Between Computation and Intuition, *Journal of Design, V.8: Interface 2013.*
[7] **Romvári, P**., (2011): Parametrikus tervezés a gyakorlatban*,* Építészfórum, http://epiteszforum.hu/*parametrikus-tervezes-a-gyakorlatban*.
[8] **Yabi, W.,** (2013): Parametric Design for Architecture, Laurence King Publishing, City Road London.
[9] **Schumacher, P**., (2014): Design Parameters to Parametric Design, in: Ed.: Kanaani, M., Kopec, D., Routledge, T., Routledge, F.:The Routledge Companion for Architecture Design and Practice: Established and Emerging Trends, New York, 2016.
[10] **Lynn, G.,** (2009): Recycled Toy Furniture, Greg Lynn FORM, Architectural Design, oldal 94-95.
[11] **Sokol, D., Mafi, N., McLaughlin, K.,(**2018): 27 11 2018. [Online]. Available: https://www.architecturaldigest.com/gallery/best-of-frank-gehry-slideshow
[12] **Krizsán, A**., (2024): A gondolat szépsége, The Beauty of Thought, *METSZET, 15 (4). oldal 32-37*. ISSN 2061-2710, https://doi.org/10.33268/Met.2024.4.4
[13] **Botzheim, B.,** (2021): UFO a parkban, Hungexpo F1 fogadóépület, *OKTOGON, 170, Vertigo Publishing, Budapest*, https://www.octogon.hu/epiteszet/ufo-a-parkban-hungexpo-f1-fogadoepulet/
[14] **Botzheim, B., Gidófalvy, K., Kikunaga, P. E., Szollár, A., Reith, A**, (2016):Performance-oriented Design Assisted by a Parametric Toolkit- Case study, in: CAADence in Architecture, Back to command, Proceedings of the International Conference on Computer Aided Architectural Design, Ed. Szoboszlai, M., (2016) Faculty of Architecture, Budapest University of Technology and Economics, Budapest, oldal 213-220.
[15] **Zukowsky, J.,:** Zaha Hadid British Architect, Encyclopaedia Britannica, 2023.06.30 https://www.britannica.com/biography/Zaha-Hadid.
[16] https://www.octogon.hu/design/nem-hasznalom-azt-a-szot-hogy-futurisztikus/
[17] Studio Oberhauser https://www.studio-oberhauser.com/design/product-design/chair-none/
[18] **Gardner, M.,** (1987): Penrose Tiles to Trapdoor Ciphers, The Mathematical Association of America, Washington, D.C. 2nd edition, 1997.
[19] **Smith, D., Myers, J. S., Kaplan, C. S., Goodman-Strauss, Ch**., (2023 preprint): An aperiodic monotile, A Chiral Aperiodic Monotile, https://arxiv.org/abs/2305.17743
[20] **Smith, D., Myers, J. S., Kaplan, C. S., Goodman-Strauss, Ch.,** (2023): An aperiodic monotile https://cs.uwaterloo.ca/~csk/hat/
[21]°Extrudr ,https://www.extrudr.com/en/products/catalogue/greentec-pro-carbon_2410