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A METHODOLOGICAL OVERVIEW OF PARAMETRICISM: LESSONS FROM A CASE STUDY

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Abstract: *The aim of the study is to introduce the concept of parametric approach in architecture and to show its use in finding appropriate shapes for different projects. Also, the evaluation of theoretical tools for studying parametricism will be discussed. In the first part we briefly introduce some representative flow in modern architecture related to parametric design. The misuse of the word "parametricism" will be explained, too. In the last section a case study of our work will be presented. The point is to illustrate how the investigation process of the logical system of a new plan is being developed and how the space accentuates as a core of new extensions. The interpretation of this case study will show the limits of parametricism. Also, the biophilic design will be introduced as a complement of parametricism.*

Keywords: theories and manifestos, design methodology, parametric architecture, generative design, biophilic design, robotics, manufacturing, Patrik Schumacher, Zaha Hadid.

1 NEW METHODS IN ARCHITECTURAL PLANNING

Most people use computers nowadays. This advance in technology has also meant a huge leap for architects. There is a lot of architectural software which makes the workflow much easier and quicker than the previous methods. Without these programs today's architects would have a much more difficult time. Usually there is more than one program used to create one plan, as each program has its own advantages. These programs offer the opportunity to create models and layouts involving complex geometries. It is now possible to engage non-Euclidean geometries that go far beyond traditional architectural plans. These opportunities require a new thinking method and a new style.

The focus of this work is to clarify and deepen our understanding of the parametric design and its role in architecture. Research supports the development of a new unified style of modern architecture based on parameterization and those theoretical principles that form the basis of parametricism. The *Parametricist Manifesto*—which was created by Patrick Schumacher (2008)—will be scrutinized in this context. Furthermore, it will be analysed in buildings and constructions.

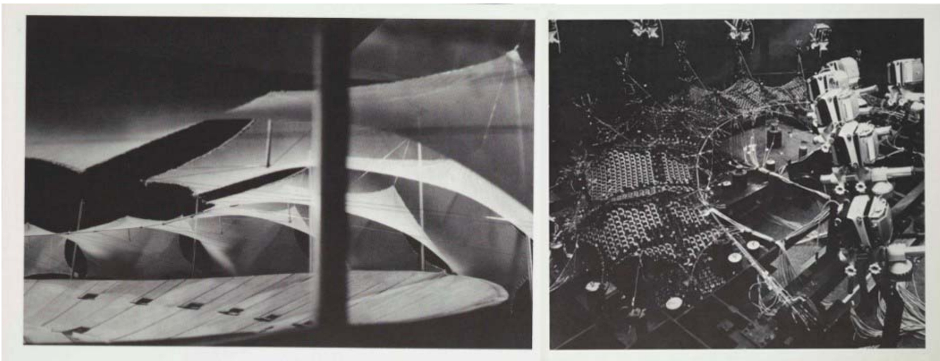
In the second part of the paper we introduce the actual, yet unrealized, plans of the Jedlik Ányos Gimnázium (JAG High School) in Budapest. The modelling process of this project is parametric, but the style of it is not clear in parametricism. It is a school where there are a lot of children each day—children who live their weekdays in this building. That is why in this building the psychological effect of the spaces has special importance. Parametricism does not have any set rules in the psychology of spaces. That is why it was a good solution to use biophilic design elements in that project. Parametricism is based on mathematics and programming. The biophilic design came from the field of social psychology. Our main goal is to demonstrate how parametricism and biophilic design can be used in the same project, and why they complete each other.

2 ANTECEDENTS OF A NEW PARADIGM

> "The enumeration of the parameters, scientific research, the quantitative mathematical analysis of these parameters, these form a task to be tackled *a priori* by the new architecture in every case. There will thus be born that architecture I have long demanded, and to which I gave the name parametric. Its ineluctable geometrical character, the rigorous interconnection of its forms, the

absolute freedom of phantasy itself which can spring up where equations cannot fix their own roots all this will give it a crystal splendour." (Moretti, 1951)[1]

Italian architect Luigi Moretti in the 1940s interpreted parametric architecture as a system that determines the relationship between parameter-dependent sizes. He could be the first architect who defined this style as a parametricism. This way of thinking is based on existing definitions of parts and elements in a model. However, the first building that is usually mentioned as an "antitype" of parametricism is the Munich Olympic Stadium (Figs. 1 and 2), which was built for the 1972 Summer Olympics.



Figures 1 and 2: Study and stress models on Frei Otto's Olympic Stadium in Munich, Germany. (Ludwig Glaeser, New York, 1972)

This structural wonder was designed by Frei Otto and Behnisch and Partners. Frei Otto conducted a lot of experiments with non-Euclidean geometries (Glaeser, 1972). The stadium is a highly innovative light tent, which is one of the most iconic buildings in Munich. Frei Otto had no computational background to design this roof with software; that is why he had to build a model of it. He had the goal of creating a structure with less material and energy. He performed a lot of experiments to design minimal structures. Frei Otto researched in the field of the mast and cable-supported membranes. These examples are in regular use nowadays, but were quite spectacular when they were first created.

Consequently, new design practices led to the development of new approaches to architecture, such as the use of three-dimensional computer models. Theory-specific relationships are not limited to one method, therefore it is possible to rethink concepts

[1] English translation of the full text by Bucci and Mulazzani (2002, pp. 175–177).

that can support different processes. Parametric architecture used to be a market where criticism was restricted for people who worked with it.

In a system where software like Maya and Digital Projects required endless iterations, it seemed that architects were limited by software knowledge. They needed to apply style consultants to select the right iterations. In a networked society, architecture is an important tool for regulating urban communication to create new forms of social networks, such as networks of communication between people and places. That is why architects need to accommodate the new design methods (Schumacher, 2009).

The most familiar example of parametric design remains an extreme design created by Zaha Hadid Architects. Their design is known for rounded angles, and the lack of sheer and familiar shapes. By connecting geometry to a modelling tool known as Grasshopper, designers were able to weave shapes in such a way as to minimize wind forces on the façade. A similar pattern can be seen in the moulded glass pieces and curved glass panels. The elegant curved shapes are, of course, an aesthetic choice, yet they define an extraordinary aura, and metaphorically suggest a warped space-time continuum (Fig.3).

Figure 3: Visualization of the "warped space-time continuum" around Regium Waterfront by Zaha Hadid Architects. (Source picture retrieved from: https://www.zaha-hadid.com/architecture/regium-waterfront)

The Regium Waterfront was designed by Hadid Architects on the southern coast of Italy in Sicily. People get the impression that it may be the greatest cultural centre ever designed by the studio. For the Regium Waterfront projects the Maya software was used, which was originally developed for the film industry to simulate natural phenomena

(Schumacher, 2009). Yet, focusing on the project's equally important social aspect, chief designer Zaha Hadid (2009) concludes that:

> "I am absolutely delighted to be working in Reggio Calabria. The project will be a gathering place for people of all ages—presenting the Mediterranean's rich and diverse history with visual and performing arts to enhance the cultural vitality of the city; providing an essential venue for discussion and discourse where the public engages with the spaces and with the exhibitions. This connection between culture and public life is critical; as what differentiates museums of the 21st century from the previous century is that the client is no longer simply one patron. The client is the public—it's many people, which makes this project really exciting."

3 THE PARAMETRIC MANIFESTO

There is a global convergence of modern and avant-garde architecture that justifies the proclamation of a new style of parametricism. This style has evolved over the last 15 years. In the final analysis it has brought about a transitional period of uncertainty spawned by both crisis and moderation, and marked by a series of short episodes which have helped bring about a reckoning with postmodernism and feminism.

New architecture graduates may never have developed a project without the help of a computer—they start working armed with experience in the fields of computer science, engineering and design. Parametric modelling is also familiar to them. However, many architects and their clients are increasingly arguing that gestures of simplicity alone are not enough. The use of so-called building information modelling has grown from 28 percent in 2007 to more than 40 percent in 2012 among builders, engineers and architects, according to a report by the International Institute of Architects.

Schumacher (2009; 2010) coined the term parametricism. He focused on creating a new toolset to create a communication signal: a signal that emphasizes the development of the style, which justifies the developments itself, but without the expense of explanation. He has been pushing the boundaries of design. The architecture has moved from a simplified architecture to abstract geometries. The tools of parametricism can be applied and used in a variety of contexts, such as urban planning, urban development and urban management. Hence, digital technologies continue to develop that will spur creative organizational, creative and material innovations to match the evolving technologies that shape modern life.

4 PARAMETRIC MODELLING

Technology gives planners and architects the tools to analyse changes observed in nature and apply them to structural features of buildings and urban organizations. One of the first architects and theorists to use computers was Greg Lynn, who is working with a computer on blob-architecture. The other pioneer is Gehry Architects. They have worked with CATIA software, which was developed to plan airplanes. The Gehry Architect has already modelled the Fish in Barcelona and the Guggenheim Museum in 3D, in the nineties.

Parametric design is a design system that allows the designer to play with certain parameters to create different types of outputs, creating forms and structures that would otherwise be impossible. CAD tools like Grasshopper use geometric programming and a complex alphabet to allow architects to take a building, reshape it, and tailor it to their needs. With their programming language, these tools allow an architect to select design outcomes, set limits, connect data and create countless elements and products for buildings in a matter of minutes (Schumacher, 2009).

Parametric scriptwriting tools are used to design a building or a city, a process which can often seem daunting; but parametrical engineering procedures have proven to productively engage with many of the challenges that architects face today. So far, the knowledge of this new style has been largely confined to architecture. The term parametricism has gained traction in architectural discourse, but critical doubts have also surfaced. Human intuition invented architectural forms, and computers have not kept up with this ability of human intuition. Today, to some extent, this assertion is agreed upon by many leading designers who have been involved in parametric design over the last ten to fifteen years.

5 ROBOTIC MANUFACTURING AND 3D PRINTING

In the field of construction there are also new technologies. When discussing the future of smart design and devices, the innovation of 3D printers and robotic hands are touched upon (Bi, Lin and Zhang, 2010). Many industry players are developing robotic arms that can perform 3D printing (Fig. 4). For example, Viridis3D recently created the M123 3D printing system, which connects ABB's industrial robotic arm to an inkjet head, enabling them to create sand shapes.

There are several other interesting developments in this field. Another example to combine 3D printing and robotics is to create an integrated solution in industries, where the robots help with printing at different stages of production. This is exactly what Stratasys has done with its 3D robotic harvester, unveiled at the IMTS trade show in 2016. The extrusion head based on their F1 technology has been integrated with the company's F3D printer, enabling the creation of a high-quality, low-cost and highly accurate 3D-printable product (Caliendo, 2016). A good example is the US-based 3D printing service, which has created an industrial robot that automates the manual process of replacing printing plates, increasing factory productivity.

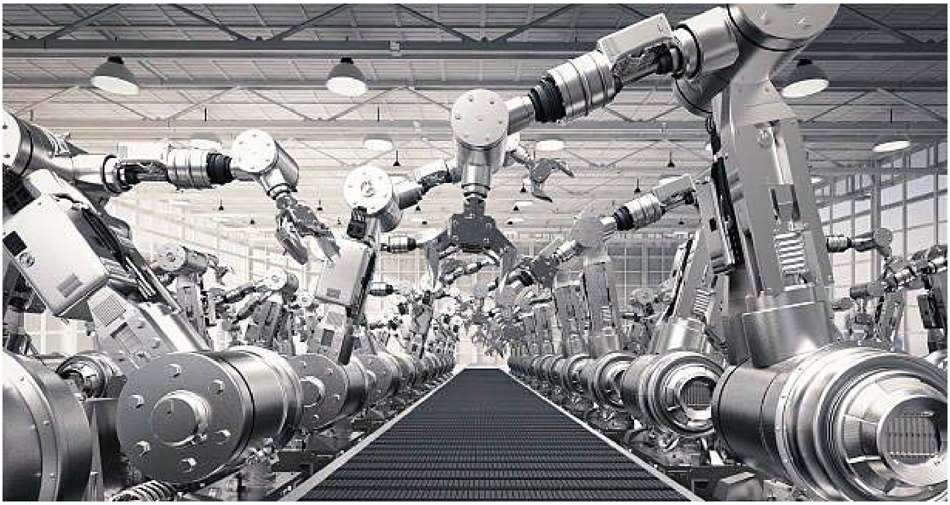


Figure 4: Combining 3D printing and robotics to create smart factories.
(Retrieved from: https://amfg.ai/2018/08/15/3d-printing-and-robotics-create-smart-factories)

The combination of robotics and 3D printing is beneficial in terms of better material management. Industrial robots are automated machines, but 3D printing can move freely, which further expands the freedom to create complex objects. If this means that the objects made with robotic 3D printing must self-support, then the problem can be solved by reorienting the construction platform and making canopies possible (MacCurdy *et al.*, 2016). The advanced 3D metal printing platform, capable of selecting and assembling a variety of different types of metal, such as steel, aluminium, glass and plastic, is now commonplace in conventional manufacturing due to its scalability and flexibility. The use of 3D printing in the robotics industry has taken many forms, and deserves special consideration (Moore, 2019; Spiegel, 2019).

Some of the world's largest manufacturers are already using 3D printers to create robots that they use for their manufacturing processes. Prada currently manufactures a range of high-end clothing and accessories, such as dresses and shoes, but they are also using robots in their production processes, as well as in other areas.

Figure 5: Interior of JAG high school. (Modelled and rendered by Levente Gyulai, 2018)

6 AN EXPERIMENTAL CASE STUDY

JAG high school is located in the Csepel district of Budapest. In the city it is the 44^{th} best high school. With around 700 students it is considered the biggest school in the district. In 2018 a government decision made it possible to create an extension for the building, creating new social and activity spaces. Pupils are learning two foreign languages: they can choose from English, Russian, Spanish, German and Italian. The main profile of the high school is the IT centred teaching, because the sector is intensively growing and its rapid development is very likely in the future.

The extension plan by Zoltán Reznicsek, Anett Mizsei and Levente Gyulai is based on a matrix. This is a new space composition with a great wing. It contains the main hall and social space with 3 more additions: a canteen, a presentation and exhibition space and a sports facility. The main element of the composition is the new wing with a wooden shell structure. This non-Euclidean, inspired form refers to Einstein's space-time continuum analogy, which is one of the foundational principles of modern physics and modern computational systems (Lynn, 1999, pp. 9–41). In the following description we attempt to explain how exactly it was created and what complications the team had while solving its structure. Furthermore, we are going to show the translation of the spoken analogy to architectural design.

The investigation of the process is also shown: how was the logical system of the new plan developed and how this space was accentuated as a core of the new extension. The main two parts of the design process were the following:

1 Planning using parametric and generative techniques,

2 Analysing design through 3D interior and exterior visualizations with the main aspect of visual, structural and conceptual integrity, connectivity, handling, look and feel comfort, sustainability, accessibility, integration, safety, scale, history and stability.

This case study is an empirical analysis. The most essential goals of the study are the practical illustration of parametricism and biophilic design together, and the revealing of the relationships between elements and the development of design solutions in the form of a system of diagrammatic criteria. Biophilic design is a paradigm aimed at intensifying connections between nature and planning, and is used all the way from large-scale urban environments, or even cities, to a single showroom or pavilion. The diagrammatic analysis of the design focuses on the content, as well as the strategic, usability and engineering considerations. This article takes a step beyond the comparative analyses and visual interpretations of three-dimensional simulations. It has an open, direct and subjective approach to show image conversions, which could be an effective method in the age of digital technology.

It is essential to integrate digital and *analog* imagery. While many techniques have been developed to achieve this effect, for this project only some of them were chosen. The software programs used were determinative. The aim of these programs was to bring a new image to life. The photo encompasses everything about contextual approaches, including which approaches could be very different. For example, in some cases the technical side, in other cases the arty side, exerts a greater force. This opportunity and diverse methods make the design process fully flexible and much faster. This means that a new version can be built in hours instead of weeks or even months. The ability to quickly build complex structures and many more features will make it easy for everyone to get started and be part of the transformation. The procedural method in design enables easy overall changes, such as refining or fine tuning without a major change of code being made.

After that the system continues to verify the correctness of the methods and analyse any bugs. Tests will be run to determine if there is any fault in the plan, and a final test will confirm that all problems have been corrected. For tests involving higher-level languages like Python, some libraries and even internal applications are often not written in a proper programming language and need to be tested more thoroughly. This leads to increased costs, as the test designer must begin to write code in the languages or libraries to take advantage of the higher-level tests.

Of course, these issues are rare and only occur at an extreme level of complexity. Generative design in architectural design is highly effective. However, these optimal design principles are based on empirical data and experimental design and are specific to a single strategic decision. More fundamental questions are yet to be resolved in this field. One of these questions is which concepts and principles most accurately match those found in more general decision-making and which principles are specific to the evolution of the design.

Spaces in the case study involving the weighting of functions: As it has been said, the main part of the extension is the new main public space, which is a multipurpose core. It is installed on a new main axis which is set to the old building's centre of gravity. The other user spaces are rooted in this hall, not only by a logical connection, but with a building forming toolset.

Designers needed to find a solution that could create a possibility to cover the main atrium. After analysing the space attributes, it became apparent that the application of some kind of concave or vault-like shaping was inevitable in order to deal with the high wingspans between the bearing walls, pillars and columns. Of course, it is not enough to find simple solutions to a problem. Solutions also have to be sufficiently elegant to reach a satisfying outcome while maintaining good visual quality. Jedlik Ányos, the Hungarian scientist, is well-known for his discoveries in physics, so the team started to investigate an analogy for that. It then could be used as a base for the building's morphological concept.

Modern physics describes the space-time continuum theory, which is based on Einstein's relativity theory. It is a mathematical model that creates a connection between space and time, and visualizes some kind of structure behind the universe. A 4-dimensional coordinate system, with 3 space dimensions and a time dimension, constrains us. The classic Euclidean coordinate system was superseded by Minkowski's geometry, in which the spectators' time and space perception is expressed with a formula known as the Lorentz-transformation.

The simplified variation says that the material (weight) has a warping effect on the space-time continuum. This is exactly what Einstein explained in his theory regarding the nature of space and time in gravitational field, which led later to the recognition of famous concerns about black holes. Extraordinary gravitational fields can be easily visualized by using a Riemann shape. This was used for the form and space propagation throughout the whole project—even when designing the shell structure of the main atrium.

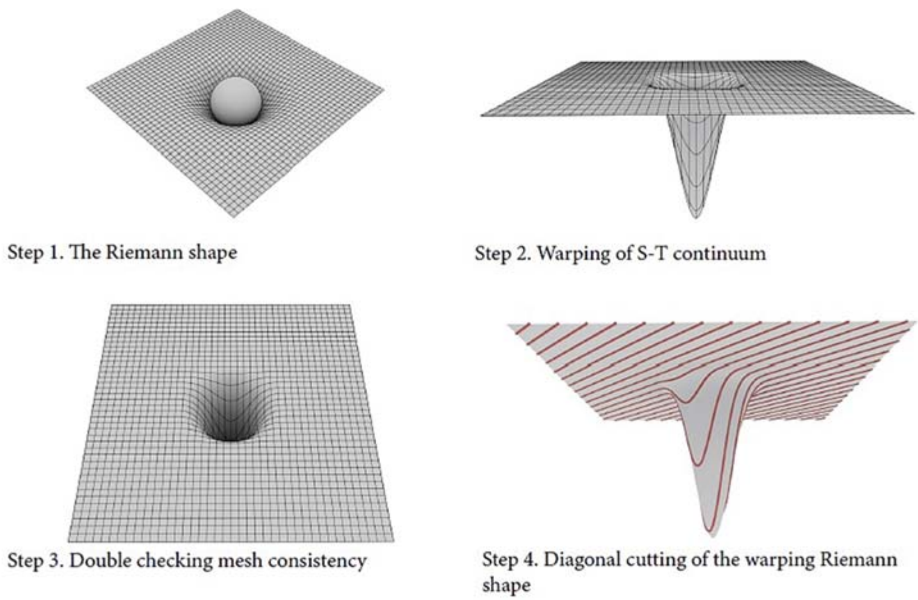


Figure 6: Conceptual shapes of JAG's Riemannian surface and its complex curvature.

Here we have an infinite space of 4 dimensions where the magic of quantum mechanics can manifest. These 4 dimensions can be assumed to be a conventional set of coordinates (X, Y, Z), and the larger dimensions can be assumed to be extra dimensions that distort the surface of this 4-dimensional space. So our 4-dimensional space can be described by 2 equations and 3 vectors. Even our 4-dimensional space as in our 2-dimensional space seems to show signs of deformation, but as the extra dimensions in our additional dimension are 3-dimensional, such a deformation is subtle.

On *Figure 6* a link is shown to a magnetic field PDF (relativity, vector addition, three planes, and an imaginary line, starting with a right-handed compass) that is represented in a 3-dimensional geometry (Step 1) by the shape of the plane, with a central point that could be described as a configuration of local spherical geometry that is the generator of the magnetic field.

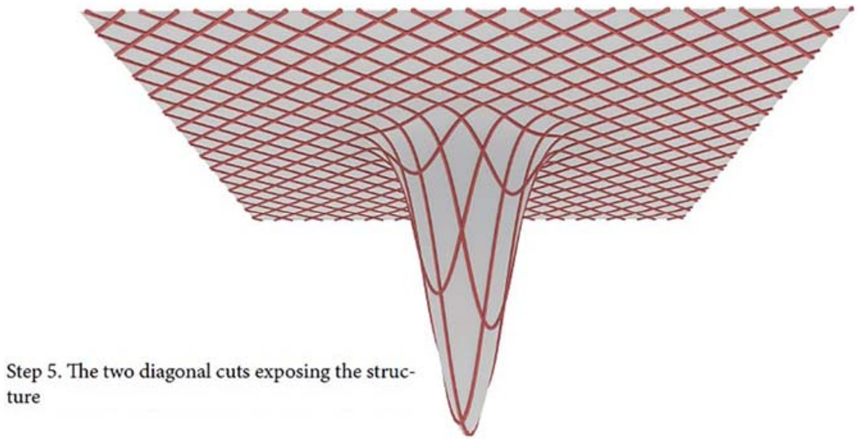


Figure 7: Conceptual shapes of JAG—a quasi-Riemann surface of complex curvature.

Figure 7 and *Figure 8* show quasi-Riemannian surface of complex curvature. An object showing a complex curvature that lacks complex time is also referred to as a spinor. The construction of the spinor illustrates the characteristic features of a spinor. The concept of spinor is similar to the normal angular momentum principle: the fact that two identical spinning objects attract each other because they are attracted by a specific property of both objects. The spinor acts like a normal angular momentum machine and creates a force on its source. It changes its angular momentum (momentum direction).

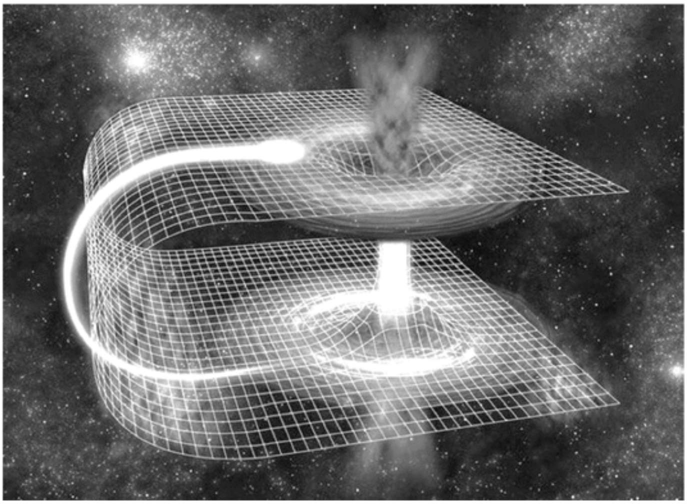


Figure 8: Warping of the space-time continuum creating a non-Euclidean form.

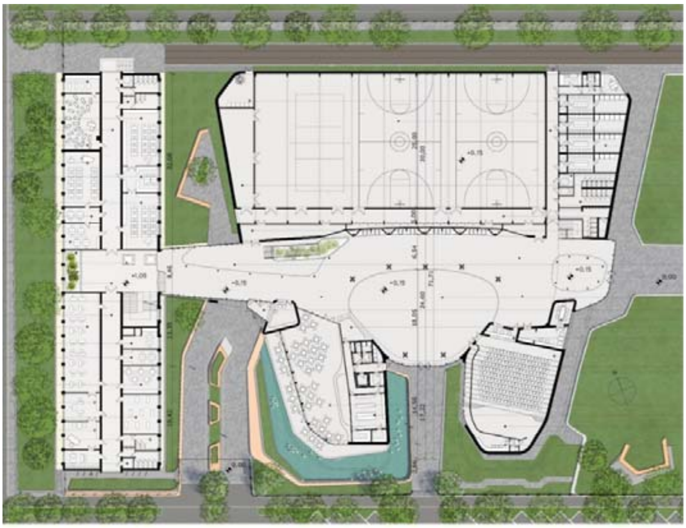


Figure 9: Floor plan of JAG. (Courtesy of Zoltán Reznicsek, Anett Mizsei and Levente Gyulai)

As the previous images show, the plane cutting method of translating the Riemann shape into an architectural structure was the way to define the structures. The inner bearing structure has an exterior layer which mixes glass panels and TiZn panels to get the higher amount of natural lighting in the interior. A shadowing panel system is modulating the optimal lighting of the interior. As it was not possible to load the wooden structure with the second-floor corridor, the planning team designed a reinforced concrete row of columns to carry the weights. It was important to shape the columns to fit the wooden shell.

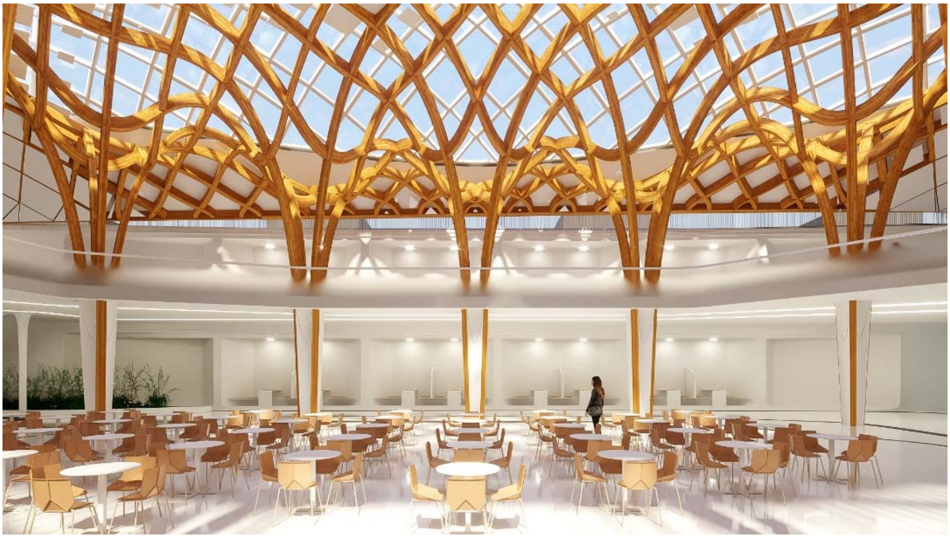


Figure 10: The main hall of JAG. (Modelled and rendered by Levente Gyulai, 2018)

Accordingly, the building acquires a natural, organic outlook. All the columns positions were designed to create the largest free space available. This was a major step to multifunctionality and flexibility from the perspective of space usage. The clear light-grey, semi-glossy epoxy floor with a moderate index of reflection also contributes to multifunctionality by resulting in a neutral interior space (Fig. 10). There was a secondary meaning coded into this effort: referencing the torus like space-time continuum, and recreating the Riemann shape visually by mirroring the weight, caused warping. The whole building plan and construction were following the main analogy, as in the Riemann shape's similarity to DNA. As the floor plan shows below, the other functional extensions are connected to the main atrium as a quasi-Riemannian surface.

7 SUMMARY

With the current content, though, we think a blend of procedural generation would be necessary. Note that we are not declaring that generating randomly is inherently bad. On the other hand, we see no fault in establishing a body of knowledge which is beyond those designers who do not understand the scientific process. It is a good example to show that the architectural aesthetic approach may be far more elegant than the "art for art's sake" approach. Despite its elegance though, it is not easy to understand.

The design team is going to do more procedural designs in the future. We expect to find that these designs efficiently scale up to meet our demands in terms of architecture, civil engineering and graphics. It is a basic aim to create spaces, where people like to live. In the last part of my paper, we should analyse the psychological backgrounds of these rooms.

7.1 Why wood?

According to certain researches not too far in the past (Rice *et al.*, 2006) "a Canadian study showed that wood in interiors was perceived by a majority of subjects as more 'warm', 'inviting', 'homey' and 'relaxing' than all other tested materials. […] The top-rated rooms in the study were completely wood dominated, containing little to no artificial materials and having large windows with views of nature, while the bottom five rooms were characterized by a marked lack of anything natural, and the lowest-rated room of all, a modern living room, was perceived as 'cold' and 'uncomfortable' by most respondents. A positive emotional response to wood was not universal, however, a large majority of subjects in the study expressed sentiments favouring wood."

7.2 Why patterns?

Patterns also can evoke the biophilic effect. We agree with Nikos A. Salingaros (2012) that "much, if not all, of the natural structure is fractal". His definition of fractals does not demand a strict mathematical interpretation of fractals—infinite repetition is not necessary, only a scaled self-similar pattern. Salingaros builds his theory on the investigations of Christopher Alexander, Sara Ishikawa and Murray Silverstein (1977), and admits that visual fractals in the environment mitigate physical stress and may even have a healing effect, based on other research. This is in contrast with the modernist ethic, which favours a stark minimalist or abstract look. Salingaros (2012) points out that a majority of people feel uncomfortable or stressed in its surroundings, and argues for evidence-based design rather than “a largely mythical industrial efficiency.”

7.3 Why natural light?

Several studies have focused on identifying design elements that correlate with improved learning outcomes in schoolchildren. According to the U.S. Department of Energy’s National Best Practices Manual for Building High-Performance Schools, daylighting classrooms is the cornerstone of best practice in school design. This is supported by research: student learning rates in daylit classrooms have been measured at levels up to 26 percent higher than those of students in classrooms that were not daylit (Heschong-Mahone Group, 1999).

The design philosophy of JAG was based on surveys, investigations and research instead of architectural style-dictated regulations and manifestos (Schumacher, 2010). The fundament of this type of design is research. Moreover, the studio was focusing on the creation of architectural spaces that support humans’ well-being and mental health. Designers should find the connection between parametricism and biophilic design to have the ability to create quality and sustainable houses. While parametric design allows us to reach a new level of design and construction, the designers also need to keep human-scales in focus.

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