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EXPLORING THE ROLE OF PARAMETRIC ARCHITECTURE IN BUILDING DESIGN: AN INCLUSIVE APPROACH

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Abstract. *One of the design challenges that architects and designers encounter during the creation and design stage of structural concepts is the parametric optimization of an architectural object's form. It is a very time-consuming and difficult process to evaluate a building's energy performance as a design consideration in the early design stages. To solve performance-related design issues, a number of tools and techniques have been created during the past few decades, primarily employing multi-objective optimization algorithms. The ability to dynamically control geometry and components using parametric modeling enables the designer to simultaneously evaluate several alternatives. The system research in the fields of architecture and urban planning aims to provide the energy efficiency of a design while enhancing its performance features. Theorists' perspectives have recently overlapped and diverged over how to strike a balance between technological capabilities and environmental factors in order to create an objective architecture in terms of performance that is unconcerned with form without content. All of these factors combined to create a modern architecture that is conceptually distinct from earlier tendencies seen before the advent of digital technology. In this paper, the relationship between the parametric architecture and environmental friendliness on building design has been explored. In order to analyze the theoretical study data, this research paper aims to elucidate the key elements of parametric architecture. This paper also reviews the utilization of cutting-edge implementation techniques, contemporary building materials and digital design approaches resulted from the parametric design in the growth of architectural philosophy.*

Key words: *Parametric Architecture, Building Design, Contemporary Architecture, Digital Design, Energy Efficiency, Sustainability*

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1. INTRODUCTION

The demand for sustainable structures is growing, according to a construction study. This is because building operations account for 40% or so of CO_2 emissions, which are directly correlated with the amount of energy used in construction to maintain the degree of user comfort. Increasing a building's energy efficiency is what architects aim to do [1, 2]. There are numerous places, in particular, with extreme climatic conditions such as significant daily or seasonal changes in temperature. Currently, HVAC (Heating, Ventilating, and Air Conditioning) systems are the most widely used methods for coping with this large temperature range of climate (Figure1). As a result, these places use a lot of HVAC system energy to maintain indoor thermal conditions within predetermined temperature ranges. In other terms, it is estimated that the energy used by buildings accounts for almost 24% of the energy used by the planet overall [3, 4]. Concern over the current situation necessitates the development of more energy-efficient construction techniques [5]. In terms of the built environment, the idea of sustainability is not a recent one; it developed from the 1970s' ideology of suitable technology and environmental consciousness. It is obvious that some principles should be taken into account during the design stage, notwithstanding the concept's developmental history and the variety of opinions on how sustainability could be operational with regard to the built environment [2, 6]. According to studies [2, 7], supporting sustainable design by raising initial investment costs by around 2% results in a nearly 20% reduction in building costs.

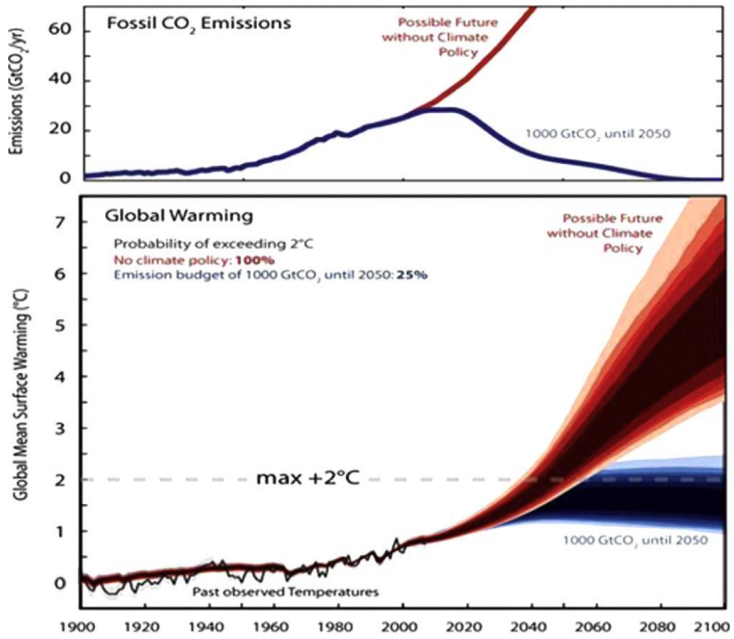

Fig. 1 Global warming and CO_2 emission.
(*Source*: https://www.newscientist.com/article/)

While global warming and the security of long-term energy sources have an impact on our planet, it is crucial to establish strategies and guidelines to reduce energy usage [8]. Additionally, there are restrictions now that force designers and architects to think about the energy usage and environmental impact of their projects. We feel the basic point is the architectural design rather than an external treatment like the HAVC system. All components of the structure, especially high-rise buildings with their expansive facades, have been tied to the high-tech or high-efficient HVAC system to conserve energy. Because of this, a lot of design guidelines and standards use building orientation, material selection, and other design tactics as recommendations for lowering HVAC system energy use. The development of kinetic envelopes with parametric designs that have interactive and responsive access to natural energy sources like solar radiation, seasonal wind, and other sources is the solution to this particular environment. To construct an "Acclimated Building," the resulting kinetic building envelopes should intelligently provide natural energy while reducing the energy consumption of the HVAC system.

Building sustainability and other domain knowledge were changed by the creation of Building Information Modeling (BIM). Especially, this is a BIM-based parametric design approach that uses the Autodesk Revit Application Programming Interface (API) for BIM authoring. Therefore, using energy simulation tools throughout the design phase may be one of the best options for analyzing the energy performance of buildings [5, 9]. The simulation application "Autodesk Green Building Studio" allows designers and architects to effectively apply parametric patterns to buildings. With the aid of this energy-analysis software, designers and architects can undertake whole-building analyzes, optimize energy usage, and begin the process of creating carbon-neutral building designs. The software completes the energy analytical model by adding defaults and assumptions based on the building type and location, assisting designers in carrying out a reliable and valuable analysis for decision-making. For architects to construct a calibrated energy model for their ideas, this software automatically gathers historical weather data from the same time period [10]. As a result, green ideas and methods have advanced as sustainable concepts, and the idea of environmental preservation has also been taken into account in the construction plan. Although there will be a difference between the simulation's outcome and the amount really present in the building, this difference can inspire designers and architects to come up with more energy-efficient solutions [11]. In this paper, the relationship between the parametric architecture and environmental friendliness on building design has been analyzed. This paper also explores the utilization of cutting-edge building techniques, latest building materials and digital design approaches resulted from the parametric design in the growth of contemporary architecture.

2. RESEARCH METHODOLOGY

In order to define what sustainability means for constructed facilities with respect to energy efficiency and parametric designs, this study offers a framework for categorizing resources related to building environment sustainability and evaluates a cross-section of existing literature. In this paper qualitative research method has been used. The systematic literature review explores the basic concepts and backgrounds of parametric architecture through books, internet and secondary data from relevant published academic literature from journals articles and research papers. In order to analyze the theoretical study data,

this research paper aims to elucidate the key elements of parametric architecture. The data collection in the qualitative research are the data that comes from a number of case studies and examples that are described descriptively and are supported by illustrations and photographs to reinforce the arguments put forward. By showing commonalities and exposing the differences among implicit conceptions of built facility sustainability expressed in extant parametric works, the paper aims to provide a starting point for continued built environment sustainability research. The paper's conclusion is a list of criteria that can be utilized as a starting point for future research and application to further define the idea of sustainable built environment.

3. INTERPRETATION OF PARAMETRIC ARCHITECTURE

Digital media has been employed in architecture in a variety of methods during the last fifteen years, which has had an impact on the entire building and design industry. Digital media was first only used as a medium for representation. Architecture has discovered a new instrument for conceptual design in digital media thanks to developing digital technologies [12]. Although the meaning of the phrase "parametric design" may seem simple, it is really somewhat difficult to explain. This phrase indicates using parameters to your advantage when building a form. "A technique based on algorithmic thinking that enables the formulation of parameters and rules that, together, define, codify, and clarify the relationship between design purpose and design response" [13] is how W. Jabi characterized parametric design in 2013. The use of the relationships between the patterns, however, is the main problem [14].

The major benefit of parametric, generative, or algorithmic design is its effective use of scripting to flexibly describe and create geometry, linking choice variables to geometry. Two fixed features referred to as constrained and variable attributes and designated parameters are part of the geometry itself. In order to develop a fresh solution to the problem, the parameters in the parametric model are altered. Without wiping or redoing anything, this model adapts to changes by adjusting or reconfiguring to the new values of the parameters [15].

The previously "invisible" mathematical and geometrical procedures, forms, and structures are now visible and useable by architects since they can be understood spatially. Architectural design has developed computational ideas such as topological space (topological architectures), isomorphic surfaces (isomorphic architectures), motion kinematics and dynamics (animate architectures), key shape animation (metamorphic architectures), parametric design (parametric architectures), genetic algorithms (evolutionary architectures), or fractal geometry (fractal architecture) using new techniques [16].

Visual programming (VP) systems were created to help designers while creating scripts to create parametric models. Since then, it is evident that VP systems have significantly changed, with tools like Grasshopper, Dynamo, and Generative Components making parametric modeling more and more accessible to the design practice [17, 18, 19]. Typically, in parametric design, the form is influenced by the values of the parameters, and the relationships between the forms are described by equations. As a result, interdependencies between forms can be discovered and their transformational behavior can be identified (mathematically and geometrically).

Although there are many benefits to using parametric design in the construction sector, the main focus of this research is on organizing and combining the needs and connections of various design aspects into a single specific form. This method aids the architect in quickly and efficiently analyzing a wide range of potential solutions [20]. Numerous design characteristics, including functional requirements, structural requirements, and user needs (Figure2), can be used to specify the development of parametric buildings [21].

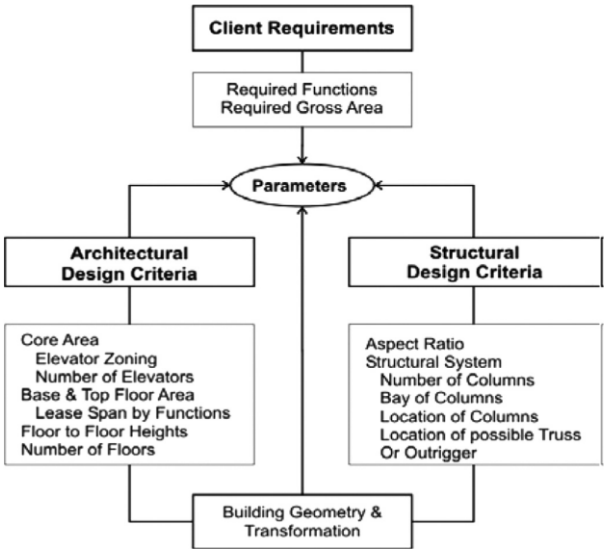

Fig. 2 Design Parameters
(*Source*: https://www.researchgate.net/)

3.1. Evolution of Parametric Design in Architecture

Algorithms are the basis for parametric design in engineering. It can be summed up as the solution to any problem and the required input and output procedures. Additionally, the parametric design depends on appropriating and repurposing measurements and information from nature. As a result, it shares a tight relationship with morphology, the study of the forms and purposes of plants, living creatures, and non-living things represented by rocks that have beautiful geometric patterns. Morphology is a major inspiration for architectural design [22]. Parametric design is a type of contemporary avant-garde architecture that replaces Current and Postmodern architecture. The term "Parametricism" was coined in 2008 by Patrik Schumacher, a collaborator on Dame Mohammad Zaha Hadid's architecture [23]. In the 1960s, pragmatism as a design trend began to take shape. Antonio Gaudi (1858–1926) of Spain and Frei Otto of Germany were two of the earliest architects to use it (1925 - 2015). These two tried to figure out how to get curved shapes, which are utilized to create the ideal shape for domes and curved surfaces, using techniques similar to those found in nature [22].

Zaha Hadid, a British-Iraqi architect who lived from 1950 to 2016, is credited with helping to establish this style of architecture and art. She stood out for her capacity to reappear and take on more daring and free-spirited shapes, solidifying the dynamic and abstract idea of mass in three dimensions. Her designs were marked by curves and

oblique lines, moving away from straight architectural lines and right angles. She achieved this by introducing oblique and sloping forms into the vocabulary of architectural design, earning her the titles "Queen of Curves" and "Abstract Woman." Her colleague, German architect Patrick Schumacher, adopted her method because he thought parametric architecture was capable of integrating all architectural elements and transforming them into elements or unitary logarithms.

4. Environmental Compatibility and Parametric Design

General concept shape plays a significant role in the parametric design of buildings, having an impact on both the functionality and aesthetics of the structures. By using expert systems and the principles of form, the development of parametric modeling approaches has made it possible to reconcile design functions and geometry. Performance-based design methodologies result from the geometric model's change and performance evaluation. However, creating the building shape when trying to meet the aforementioned criteria is a difficult task. A single, straightforward adjustment to one aspect can have an impact on other factors, which must be taken into account while constructing the project, according to the functional requirements for construction [24]. The goal of sustainability can be achieved in so many different ways. For example: utilizing various materials, utilizing the most advantageous solar orientation to receive the most daylight, thinking about more energy-efficient buildings, such as bionic, and so forth [20]. These factors produce significant advantages. They include a reduction in greenhouse gas (GHG) emissions, a 30% reduction in lighting fixtures or lighting needs, an increase in productivity of at least 30%, a 70% reduction in general electricity use, a 50% to 60% reduction in building water demands, a 5% to 10% reduction in cooling requirements, and a 36% reduction in energy consumption when compared to standard buildings [20, 25, 26, 27].

Fig. 3 Parametric design of Swiss Re Building in London
(*Source*: https://www.scienceopen.com)

The Swiss Re building in London's design process is a preliminary case study of a performance-based strategy that includes parametric design to enhance performance. The curved shape was treated using parametric design, which reduces the area of its exterior surface by 25% and, as a result, the amount of heat energy that is gained from the outside and lost via the cover. Building facade and shell modifications are made in accordance with wind load and structural performance (Figure 3). The performance of solar energy, which achieves optimal thermal performance, is structural or environmental performance.

5. Role of Technological Advances in Shaping Modern Architecture

Since the 18th century, dominant typologies have either been based on the notion that architecture should return to its natural origins—a model of primitive shelter as an imitation of the order of Nature—or they have emerged as a result of the Industrial Era, characterizing architecture as a process of producing functional parts [28]. Modernist models of functionalism and universal positivism are being directly challenged by phenomenology-based dominant conceptions in architecture throughout the Modernism revision process [29].

With this shift in paradigms and the transcendence of concepts in architecture, new methods for modern architecture design have emerged as a result of the quick growth of digital technology [30]. With the advent of digital technology, architects were able to discover architectural elements that were challenging to articulate and represent through conventional means. Along with the option for change and the detection of design flaws, while the design was still functional rather than after implementation, this tool also provided the chance to test the formation in terms of plastic design, construction, or environmental considerations [30].

A crucial design strategy in the digital design process, parametric design in contemporary architecture allows for diversity by allowing for changes in parameter values without altering the design entity [22]. By modifying or adding one of the parametric model's structural components. Virtual reality techniques, dynamic modeling techniques, and parametric modeling techniques are evident examples of architectural design tools that came along with the digital revolution and had an impact on modern architecture [30]. In many areas of environmental design, dynamic modeling techniques are used to construct the architecture. These new concepts and paradigms should aid in the construction of a model for the dynamic evolution of architectural form. As a result, the use of digital technologies in modern architecture is on the rise.

6. Generative Algorithm as a Flexible Designing Tool for Construction

Associated and generative modeling, which uses automated source code creation through generic frames, classes, prototypes, templates, aspects, and code generators to increase programmer productivity, contains the fundamental concepts of conceptual design and can be used to describe them mathematically. Such editors are closely interwoven with modeling tools in the realm of architecture, allowing designers to create form generators ranging from the straightforward to the breath-taking [31]. The defining of spatial elements (solid, plane, or surface), as well as their transformation and change, are all part of digital modeling. It is quite difficult to intervene on each individual part

because they are all directly dependent on one another, and every change in the design results in changes in the geometry. Each individual piece must be adjusted, scaled, and reoriented with any such modifications, which takes a lot of effort.

Generative algorithm modeling is a type of modeling that employs related and generative modeling. The word "algorithm" appears in the name of this method because, in this style of design, objects are created using algorithms, and their output for subsequent design phases is also created using algorithms. Grasshopper is one of the most widely used generative design editors for architectural design [32, 33]. This editor provides a variety of mathematical tools for generative modeling, including operators, conditional statements, functions, and trigonometric curves. It is coupled to Rhino 3-D models (Figure 4). There are operators for vectors, points, and planes in the area of analytical geometry. The list and data management segment are crucial since it enables thorough database manipulation. There are other advanced modeling solutions available, including VB.NET scripting and the rhino (it allows access to Open NURBS geometry). It is possible to choose from a variety of NURBS geometry alternatives and slightly fewer options for mesh objects thanks to associated element operations and analysis.

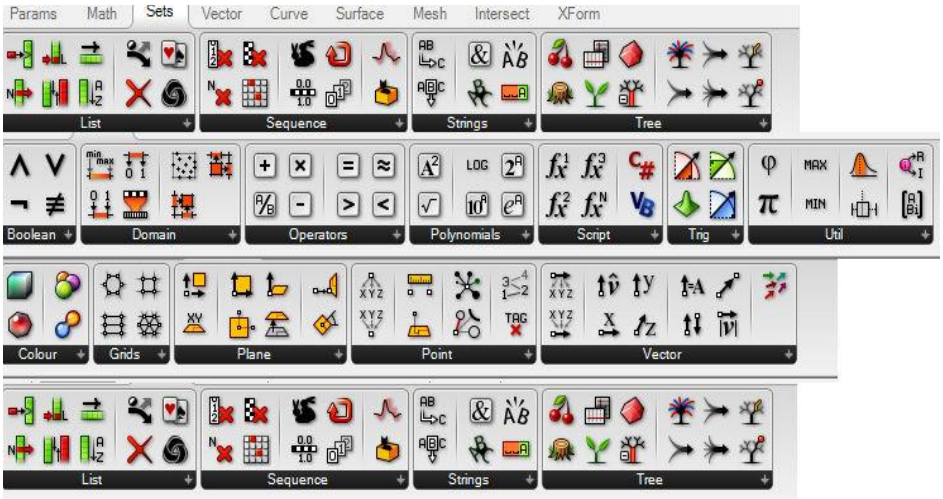

Fig. 4 Grasshopper Mathematical Operators
(*Source*: https://www.researchgate.net/)

7. WORKFLOW METHODOLOGY FOR PARAMETRIC DESIGN AND ENERGY SIMULATION

The integrated workflow methodology incorporates energy simulation throughout the initial design phases of a building by combining MOEAs with parametric modeling. In order to overcome the shortcomings of current approaches to designing bio-climatically efficient buildings, which rely on the architect's intuitive application of piecemeal measures rather than the goal of optimizing the building as a whole system of interconnected parameters, a decision support tool is introduced [34]. In performance-based generative design, rather than being the result of prior decisions, the performance of a building drives its design (shape and geometry generation, envelope materials, HVAC systems, etc.). A

Pareto-based, shape-generative method employing EAs was originally established by L. G. Caldas [35] in 2001, and indicated that solid parametric modeling tools may be used to extend it. Since parametric design drives the designer to cognitively break down the problem and when combined with MOO, makes it possible to visually watch the optimization progress, it provides the designer with direction. Figure 5 shows the methodology adopted and the required steps.

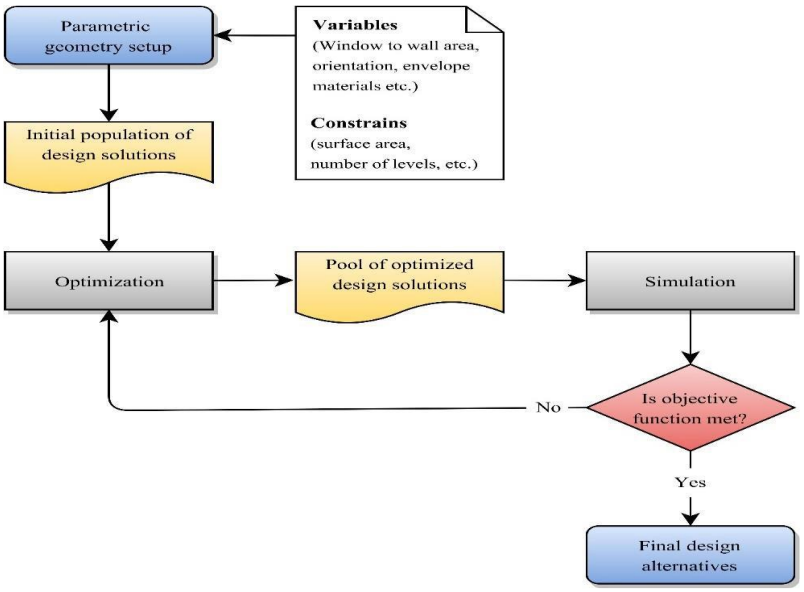

Fig. 5 Flowchart of proposed methodology
(*Source*: https://www.academia.com/)

By applying the Darwinian theory of evolution to the design options, one can find the ideal combination of values for a given set of variables by using Genetic Algorithm solvers like the Galapagos Evolutionary Solver (plug-in for Grasshopper). A pool of optimized design options that satisfy the objective function set is the end result after multiple iterations and the rejection of unfit solutions. The climatic circumstances at the construction site cannot be changed while constructing an energy-efficient structure, but the architect can decide on the building's attributes (each of which has an impact on thermal performance in a different way), such as (but not limited to):

- A general structure and form (shape and orientation)
- The Thermo-physical characteristics and material thickness of the envelope (walls, roof, floor, windows, etc.)
- Location, size, and dimensions of doors and windows
- Opening and envelope shading
- Rate of ventilation
- Internal partition walls' thickness and construction materials
- Electrical-mechanical apparatus (heating, cooling, etc.)

The designer can define rules/concepts linking the aforementioned variables and other common constraints (surface area, number of levels, etc.) to geometry by using VP tools, such as Grasshopper, Dynamo, and Generative Components hosted as plugins inside a 3D representation software environment (Rhinoceros 3D, Revit, etc.) [17, 18, 19, 36, 37].

8. MERITS OF PARAMETRIC DESIGN

Although the parametric design has several benefits, its primary use of curving, flowing lines that mimic fabric and are distinguished by their smoothness and fluidity may be its most significant benefit. This provides the design a distinctive shape that grabs people's attention. Parametric can be recognized in some ways, which elevates it to a more complex mode of design [30]. The reasons a typical architectural practice uses a parametric approach can vary. While some firms follow a competitive strategy by simply using the most recent software, such as parametric packages, the majority of firms tend to view parametric through the lens of effective functionality, such as an increase in design opportunities. The use of living geometric things rather than traditional shapes like a cube, cylinders, pyramids, and others characterizes this type of design [38].

One of the key advantages of parametric designs is that they can rigorously investigate more design choices, which has allowed them to generally discover flexible solutions to design challenges within the spaces. Furthermore, some of the benefits of parametric design would be apparent early on in the exploration of design options, unlike traditional CAD, which still heavily relies on drawing or physical modeling. In particular, the parametric design offers architects "a fantastic possibility for developing more creative forms" [38] when considering free-form structures. The significance of this new style of design lies in the fact that it expands vast and diverse horizons for the automation of construction documentation and higher levels of architectural control in production in the later stages of the design process, enhancing the creativity of designers to explore unusual forms that could not be imagined, which in the past seemed unrealistic and unattainable [30]. Reducing the amount of time spent on design exploration and the tiresome task of drawing specifics that can be taken from architectural models has cost advantages as well. In a nutshell, parametric design may close the gap between building design and construction. Finally, the use of computers in design has enabled architects and designers to give us beautiful and cutting-edge creations that are alive with movement.

9. CHALLENGES FOR PARAMETRIC DESIGN

One of the main problems that are usually brought up in the literature surrounding the topic is the capacity to establish associations between objects by defining associative geometry using equations [39]. According to Robert Woodbury, since the traditional stated actions in design were "add and delete," creating relationships has not previously been taken into consideration as a component of design thinking [40]. Designers now have the ability to "relate and mend," which are two new skills. In Woodbury's view, "relating" takes conscious consideration of the nature of the relationship, and "repairing" occurs in the wake of an erasure "when the parts that depend on an erased component are related to the parts that remain." Therefore, these two actions forced fundamental alterations in earlier systems. In addition to these problems, parametric design has a number of significant advantages over conventional design approaches.

10. CASE STUDIES

Making use of parametric design helps cut down on the time needed for planning. Sunlight and thermal comfort are examples of sustainable architecture characteristics that could be employed as design restrictions. The parametric design employs software to effectively alter and improve the product by integrating and coordinating conceptual design concurrently. Case studies of creative and adaptable projects that offer in-depth insight into bottom-up architecture and modular systems creation using a matrix of parametric alternatives are presented here with the goal of achieving sustainability.

10.1. Case Study 1: Infinity Loop, Yuhang, China

A hub for technology that is environmentally, economically, and socially sustainable, the new OPPO R&D Headquarters was designed by Bjarke Ingels Group and is located in the core of Yuhang District (Figure 6). By designing a tubular courtyard building with small but adaptable floor plans, the award-winning architecture firm reinvented conventional office slabs and enhanced the company's dynamic workspaces [41]. The southern border of the structure was extended southward to maximize solar exposure and offer sweeping vistas of the city (Figure7). Due to its distinctive form, it was able to become self-shaded, minimizing energy use and enhancing natural light, which in turn improved employee productivity and well-being [42].

Fig. 6 Infinity Loop, China.
(*Source*: https://www.archdaily.com)

Adaptive louvers that are orientated in relation to the sun's location are used to cover the facade. They will create a unique imprint specifically for the O-Tower and Hangzhou, lowering solar gain by up to 52%, lowering cooling load costs significantly, and lowering glare, reflection, and light pollution. The architecture includes a number of adaptable floor plates that are set aside for various functional programs but that also incorporate workspaces with biophilic design and communal areas (Figure 8). The architectural firm emphasized the company's endless expansion in the pursuit of excellence with a strategic design that strikes a balance between the city's rich fabric, natural terrain, and technology

ingenuity [42]. In order to maximize sunlight exposure and provide breath-taking city views, the southern flank of the building was extended southward [41].

Fig. 7 Daylight, minimize outward facing surface area of more solar exposed facades.
(*Source*: https://www.archdaily.com)

10.2. Case Study 2: Sustainability Pavilion, Dubai Expo 2020, UAE

The Net zero energy and water served as the Sustainability Pavilion's driving forces for sustainability (Figure 8). The Pavilion gives the U.A.E. the chance to highlight developments in energy production and water management for the area and spread aspirational messages about nature and technology to a wider audience [43]. Sustainability was the cornerstone of every technical and architectural choice made on the project, not just a discipline [41]. The Pavilion investigates the possibility for structures and the people who use them to be both self-sustaining and regenerative, with the goal of influencing thousands of visitors by educating them about the environmental effects—both good and bad—of the decisions they make on a daily basis [44].

Fig. 8 Dubai Expo 2020 – Sustainability pavilion.
(*Source*: https://www.grimshaw.global.com)

We can identify the primary priorities for this project as being the mix of passive design solutions, energy efficiency optimizations, on-site energy generation, and on-site water reuse. With the aspirational objective of establishing a net zero energy and water building, a few important design solutions are didactic in their prioritization on passive and low energy, low carbon systems [43]. Meeting the energy balance after Expo when in museum mode has been the main design issue for net zero energy (also referred to as Legacy mode). This is because of the anticipated program's high energy use and the requirement to produce enough energy from the on-site PV to meet this demand.

In order to meet multiple energy goals, architects used passive cooling techniques such shading from a 130-meter-wide main roof canopy, subterranean housing, and the use of high-U-value materials for the walls and roof to reduce the need for cooling [44]. The initial step in the process of energy efficiency and reduction was possibly the most important. The Pavilion only uses water from on-site sources for all of its needs. A variety of cutting-edge techniques were used, such as wastewater recycling and sewer mining, which pushed for code modifications and local authority approvals (Figure 9).

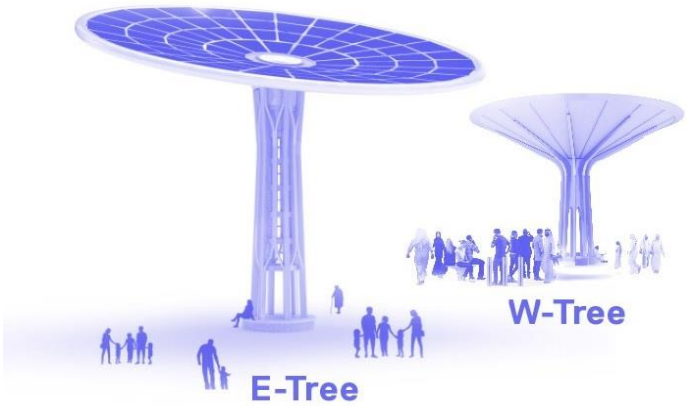

Fig. 9 Energy production and shade production of energy trees illustration. (*Source*: https://www.grimshaw.global.com)

High solar radiation or sunshine levels are both a resource and a challenge for the project. Both energy production and shade production are goals of the Energy Trees [44]. In order to generate as much energy as possible when light is reflected off of them, they also contain PV on the underside. The Water Tree allows for a passive method of dew harvesting (30 litres per day on average), taking advantage of the overnight rapid temperature change where the inner cone surface becomes cooler to generate droplets of water that gather and run down to a collection point, supporting their ecological services, including providing thermal comfort for visitors [43].

10.3. Case Study 3: JetBrains Office, Saint Petersburg, Russia

The new JetBrains workplace in Saint Petersburg, Russia (Figure10), was designed by UNStudio after winning a global competition, promotes energy efficiency, interaction, and sustainability [45].

Fig. 10 JetBrains Office, Saint Petersburg, Russia.
(*Source*: https://www.parametric-architecture.com)

The building's efficient and adaptable workplaces engage individuals and give a place to gather, talk, and work together [41]. The open atrium can be seen for the first time as staff members and guests enter the lobby. The lobby contains a number of public amenities, including cloakrooms, showers, and exercise areas. The sizable interior atrium with vertical steps serves as the hub of the new JetBrains community. A translucent zigzag facade was selected for the atrium in order to let in lots of natural light while preventing heat accumulation. In addition to a soft acoustic shading system on the inside of the glass shell, cantilevers were also placed to shade the facade [45]. Regarding the upper and lower volumes, protruding glazed ceramic components that surrounded the outside walls serve as a covering, a light source, and a tactile feature (Figure11).

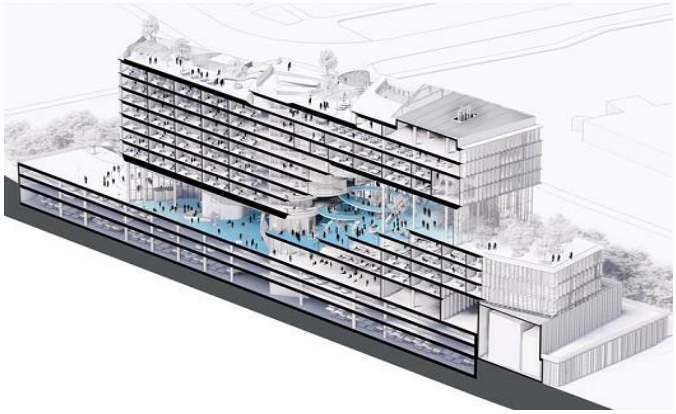

Fig. 11 Axonometric Section of Jet Brains Office
(*Source*: https://www.parametric-architecture.com)

10.4. Case Study 4: Experimental Shelter, Sibillini, Italy

Italian architectural firm Spacelab designed a parametric project that can be built without foundations on any site, leaving no trace and causing no damage to the ground at the conclusion of its life cycle (Figure 12). It is an energy self-sufficient shelter for temporary

usage. The structure, named Zero because there is no trash produced during installation or removal and it emits no emissions, may be dismantled and put back together numerous times, addressing difficulties with the circular economy, impermanence, and reuse [46].

Fig. 12 The Experimental Shelter, Italy.
(*Source*: https://www.archdaily.com)

Zero consists of three pieces: a living area, a sleeping module, and a service core including a bathroom, kitchenette, systems room, and batteries (Figure13). These three units can be combined in different ways to accommodate different space needs. A phyto purifying plant, anti-frost photovoltaic panels, thermal and hydronic heating pumps, and photovoltaic panels powered by batteries are all included in the project [46].

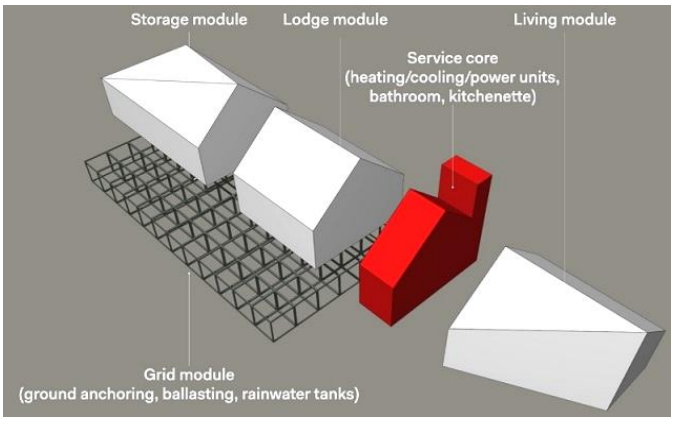

Fig. 13 The exploded module of zero.
(*Source*: https://www.archdaily.com)

11. Role of Parametric Architecture in Future Scenario

The study of building sustainability in relation to energy efficiency is made easier by using algorithm-based parametric design methods to connect building modeling and configuration to actual climatic parameters [47]. Since parametric architecture design helps to produce variety, can correct even the tiniest flaws, and can easily incorporate even the most general changes into the designs, it has been a benefit that may last for generations [48]. Different software has shaped contemporary architecture over time and has subtly made it easier to combine old and modern architectural styles. This is because of parametric architecture, many similar initiatives are about to materialize. The field of architecture has seen significant development thanks to parametric architecture. It has contributed to the creation of a physical place that will not only endure through time and the digital age, but also paves the way for more expressive and sustainable design practices [48]. In addition to assisting in the precise design and creation of our vision, parametric architecture is gradually integrating the idea of sustainable architecture, which can be very beneficial for future growth.

12. Analysis and Discussions

Buildings of all functional types require parametric optimization to increase their energy efficiency, which calls for a systemic approach and the application of computer modeling techniques. The goal of optimization is to find the best solution for an architectural structure's spatial planning and functional requirements. The efficiency criterion of architectural objects as integral systems (subsystems) of a specific hierarchical level must be established in order to discover the best solution.

12.1. Limitations and Opportunities of Parametric Architecture

The analysis of case studies and frameworks for parametric designs from the literature reveals that there are differences in both the factors taken into account and the work's intended applications. The built environment sustainability factors found in the examination of this body of material are demonstrated in several case studies. Opportunities to create resources that will bridge the gaps left by current general references are present within this spectrum. Examining the case studies has shown a number of critical issues, including the large discrepancy in the elements that are thought to be crucial for defining sustainability and energy efficiency. The built environment factors may genuinely differ depending on the problem-solving stage being addressed as well as the size and type of facility being examined. The lack of a method for evaluating sustainability in the context of built environment systems and insensitivity to contextual elements of built environment systems are other flaws in present models of the sustainability of the built environment. Although these models are an essential step in the development of knowledge about the sustainability of the built environment, their practical use for recognizing, prioritizing, and resolving issues is limited. The breadth and specificity of variables, which can range from global issues like ozone depletion to very component specific criteria like product recyclability, varied considerably from tool to tool, is one notable conclusion to be derived from this set of case studies.

12.2. Envisioning Sustainability in Parametric Design

Although the power of parametric design to generate future shapes has drawn a lot of attention, it also has a lot of promise to improve the energy effectiveness and sustainability. Variations in weather patterns, snowfall and rainfall, and other similar effects of global warming suggest that parametric design should be taken into account. These technologies are being used in the pursuit of environmentally friendly architectural designs, with energy-efficient facade design strategies and the best window sizes for illumination. It is possible to address the current demand of the hour and provide complete design solutions using modern architecture that is determined by technology and combined with a sustainable vision.

13. ARCHITECTURAL DESIGN RECOMMENDATIONS

The benefits of sustainable structures for the environment and human health are indisputable. The following recommendations are being summarized on the basis of the case studies performed and literature reviews:

- The necessity for architects to adopt cutting-edge modeling software and to call attention to fresh ideas in architectural design.
- Make use of the architectural environmental compatibility parametric design elements.
- Using cutting-edge digital design techniques in building projects.

To prepare students for the demands of the labour market, engineering and interior design colleges must teach them how to use cutting-edge design software like Grasshopper, Maya and Bellhopper.

14. CONCLUSIONS

Through evaluation of a cross-section of existing literature, this paper aims to elucidate the key elements of parametric architecture. This paper presents an overview about the relationship with sustainability, with respect to energy efficiency and parametric designs. This paper presents a framework for categorizing resources related to building environment sustainability and parametric architecture. Architectural building blocks that were challenging to represent through conventional means may now be designed with ease thanks to the quick development of digital technology and the introduction of digital media into the field of architectural design. Instead than using typical parametric design for aesthetic shaping or geometry exploration, this approach to parametric design can be a useful link between temperature, building energy, and indoor thermal comfort. A crucial design strategy in the creation of modern architecture is parametric design. Finding a suitable design for every industry, including architecture, interior design, industrial design, and others, is the focus of parametric design. As the human population works to stop global warming, create environmentally friendly energy sources, and save the planet's eco-systems, an intriguing subject that has promise for enhancing the architectural synthesis process is parametric design of energy-efficient buildings employing integrated energy simulation and form optimization with genetic algorithms. However, more research is required in this field. The construction of a holistic strategy for sustainable building design is urgently needed since it is becoming more and more necessary to handle several, conflicting objectives at once, during all phases of the design process.

In order to streamline processes, shorten modeling times, and promote interdisciplinary collaboration, new software solutions have been developed that address concerns like automation and interoperability. The huge solution space may now be efficiently explored by architects using these technologies, leading to the early design stages of designs that are optimized. As businesses turn to nature for design inspiration, they are starting to recognize the potential. It can be argued that nature serves as an inspiration for intelligent and creative engineering since it is efficient, just-in-time, the best problem-solver, the ideal example of sustainable engineering, and the ultimate problem-solver. Design process and methods, in particular as a paradigm for creating parametric designs, offer a fresh way to broaden the universe for exploring new design cases. The applications for the design methods as a parametric model generation system can be limitless.

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ISTRAŽIVANJE ULOGE PARAMETRSKE ARHITEKTURE KOD PROJEKTOVANJA ZGRADA: INKLUZIVNI PRISTUP

Jedan od projektantskih izazova sa kojima se arhitekte i dizajneri susreću tokom faze kreiranja i projektovanja konstruktivnih ideja je parametarska optimizacija forme arhitektonskog objekta. Proces procene energetskih performansi zgrade u toku razmatranja opcija u ranim fazama projektovanja je veoma dugotrajan i težak. Da bi se rešili problemi projektovanja vezani za performanse, tokom poslednjih nekoliko decenija stvoren je niz alata i tehnika, prvenstveno algoritmi za optimizaciju sa više ciljeva. Mogućnost dinamičke kontrole geometrije i komponenti korišćenjem parametarskog modeliranja omogućava projektantu da istovremeno proceni nekoliko alternativa. Sistemsko istraživanje u oblasti arhitekture i urbanističkog planiranja ima za cilj da obezbedi energetsku efikasnost projekta uz poboljšanje karakteristika njegovih performansi. Perspektive teoretičara su se nedavno preklapale i razilazile oko toga kako uspostaviti ravnotežu između tehnoloških mogućnosti i faktora životne sredine kako bi se stvorila objektivna arhitektura u smislu performansi koja se ne tiče forme bez sadržaja. Svi ovi faktori su kombinovani da bi stvorili modernu arhitekturu koja se konceptualno razlikuje od ranijih tendencija koje smo videli pre pojave digitalne tehnologije. U ovom radu je istražen odnos između parametarske arhitekture i ekološke prihvatljivosti u projektovanju zgrada. U cilju analize teorijskih podataka studije, ovaj istraživački rad ima za cilj da razjasni ključne elemente parametarske arhitekture. Ovaj rad takođe razmatra korišćenje najsavremenijih tehnika implementacije, savremenih građevinskih materijala i pristupa digitalnom dizajnu koji su rezultat parametarskog dizajna u razvoju arhitektonske filozofije).

Ključne reči: *parametarska arhitektura, projektovanje zgrada, savremena arhitektura, digitalni dizajn, energetska efikasnost, održivost*