Parametric architecture: the second international style

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T Al-Azzawi and Z Al-Majidi

Department of Architectural Engineering, College of Engineering, University of Basrah, Iraq

E-mail: tahseen.majeed@uobasrah.edu.iq

Abstract. Parametric architecture (parametric design) emerged as a concept or theoretical idea in the world of architecture around 2008, in parallel with the development of digital design tools and the rise of the new communication technologies that have spread widely in recent years, supported by the digital revolution. Many research attempts have thus been made to deal with parametric design, with interest focusing both on defining it as a philosophical and theoretical concept in contemporary architecture and as a new architectural style with specific characteristics; it may also be considered an architectural movement, or a set of techniques for the production of form at the design and implementation levels. Many attempts have also been made to define it in order to promote teamwork through collaboration between architects and other engineering specialists during the design process. This paper discusses the possibility of achieving multiple such goals by defining the notion of parametric architecture; the research problem is thus the lack of clarity of the concept or the idea of the style in terms of formal characteristics as a result of over-rapid adoption of the methods and techniques of parametric design. The research aim is to discover and explain this idea more fully, demonstrating its difference from conventional concepts of style, by comparing it with the concept of the international style that emerged based on modern architecture theories, techniques and methods during the first half of the twentieth century. To achieve this, the paper presents a set of global experiences illustrating the use of digital design technologies in different stages of production, highlighting the final characteristics of the products and what they have in common. Schumacher's dogmas and the taboo principles were thus adopted in an attempt to develop this comparison with the international style that emerged from the theories and implementations of modern architecture, and to investigate the role of modern technologies in producing its forms. The paper ends with a general conclusion that demonstrates the possibility of presenting parametric architecture and its products globally as a second international style, though currently in the stage of formation, as its fundamental principles are based on the idea of renewal and revolutionary rejection of all that has preceded it; thus, the repetition of these attempts results from dealing with the same theoretical principles and standards imposed by the techniques that produced the contemporary architectural form.

1. Introduction

New digital tools and recent computer technologies have allowed architectural design to provide buildings with new forms that facilitate new ways of thinking in construction. Based on the need and

desire to produce novelty and innovation, computer aided design systems have become increasingly parametric, offering designs that change with the input data. Such systems give more control and capability to designers, allowing the discovery of new forms and offering a better understanding of the conceptual structure of such designs [1]

Studies in recent decades have provided important information on parametric design, whether defining it as a philosophical/theoretical concept in contemporary architecture or as a new architectural style with specific characteristics; others have seen it as an architectural movement or a set of techniques for the production of form at the design and implementation levels. Many attempts have been made to define parametric architecture to facilitate teamwork and collaboration between architects and other engineering specialists during the design process, and several theories have been proposed in the literature to better explain parametric architecture; these are listed in Table 1:

Table 1. Existing research

No.	Authors	Contribution
1	Sutherland (1963)	The first use of parametric design concepts through a graphic user interface system occurred in Sutherland's PhD research, which allowed him to draw with the computer and apply changes parametrically at the same time [2]
2	Morretti (1971)	Parametric architecture is the study of "relationships between the dimensions" where a design is depended on parameters[3].
3	Kalay (1989)	Computational geometric relations automatically updated when parameters change[3].
4	Schumacher (2008)	First presentation of the concept of "Parametricism" as a style in the "Parametricism Manifesto"; this was followed by several related papers and a book named "The Autopoiesis of Architecture", in 2011, in which he introduced some principles of parametric design that must be followed to make a design parametric (Dogmas) and others that must be avoided (Taboos)
5	Woodbury (2011)	Parametric design defined as the process of exploring associative connections of geometric concepts [4].
6	Frazer (2016)	Parametric architecture moving to reformulate itself as a process in a rapidly evolving process that embraces new technologies and environmental and social purposes [6].
7	Oxman (2017)	Parametric design described as a new paradigm of design thinking. Pioneering concepts of design thinking developed, moving from typological thinking to topological design thinking in creative design, which should be considered one of the most remarkable changes in design thinking [5].

The current research investigates the possibility of achieving all of the above goals by defining the concept of parametric design, starting with the main terms and their origin, based on a research problem identifying the lack of clarity in concept or the idea of style in formal characteristics as a result of over-rapid adoption of the methods and techniques of parametric design. Accordingly, the research aim is to discover and explain this idea, then to demonstrate its differences from conventional concepts of style, by comparing it with the concept of the international style that emerged from modern architecture theories, techniques and methods during the first half of the twentieth century.

Schumacher's principles were thus adopted for the theoretical framework applied to a set of a globally selected case studies in order to clarify the meaning of parametric design in relation to the wide spread of related techniques which has led designers and researchers to adopt this way of thinking as more than just a design tool, generating a new style in architecture.

This paper offers a conclusion resulting from the analysis of several case studies that introduce the idea of international style in architecture, comparing parametric architecture with modern architecture and discussing how they have spread globally in two different periods as "international styles" based on identifying the similarities and differences between the two trends. A discussion section also summarises the results of this research to support the conclusion.

2. Parametric design, architecture, and style (Parametricism)

There are many terms associated with parametric design or parametric architecture, and these are briefly discussed below in order to clarify their meanings and use in contemporary architecture.

2.1 "Parametric": origin and history

Used since the 1650s in geometry, the word "parameter" was found in modern Latin [7]. The term "Parametric" originated in mathematics to refer to the use of variables and parameters that can be edited and manipulated to amend the end result of an equation or system. In computing, a parameter represents a variable that must be given a value during the execution of a program or of a method within a program [7].

In architecture, the word "Parametric" was first found in the writings of Luigi Morretti in the early 1940s; he wrote widely about "Parametric architecture" as the study of architectural systems based on defining the relationships between various parameters and their dimensions. However, a paper published by Maurice Ruiter in 1988 with the title "Parametric design"[8] may represent the first use of that phrase in the field.

Parametric design has affected the development of digital architectural design since 1990 [9], and in contemporary architectural practice, many parametric approaches exist. From one perspective, all designs may be considered to be parametric, as they are based on defining different parameters such as orientation, legal aspects, and solar radiation; however, the modern approach is to only consider design to be parametric if a specific tool has been used during the design process to enhance the design process by coordinating and connecting design components and parts simultaneously[10].

2.2 Parametric architecture

Parametric design is a concept that has been supported by the increasing availability of computer-aided techniques and the development of manufacturing processes which facilitate the achievement of complex forms. Parametric design as an approach relies on defining variables: whenever a parameter changes, the results change as well. It has thus been used in recent decades as part of computational design to support the design process and achieve unique design products.

Working parametrically has changed architectural practice in many ways, as it transforms all programming decisions into design decisions and thus increases the need for architects to learn new skills in order to master new techniques [11].It is also an approach that offers alternatives throughout the design process, causing the design process to emerge as a continuous, rather than discrete, process.

Parametric design also aims to identify the design process limitations found in conventional design tools by establishing relationships between different parts of designs based on the ability to edit and manipulate these relationships by observing and selecting from the results of changing them [4] .Thus, the approach requires new skills and encompasses new strategies to achieve its goals, thus changing architecture theoretically as well as in practice.

2.3 Parametricism and Patrik Schumacher

In 2008, Schumacher presented the concept of "Parametricism" for the first time in his paper "Parametricism Manifesto". He introduced both ways to follow this concept, entitled Dogmas, and things to avoid, known as Taboos in both [13] and [12] and in his book published in 2011 [14]. Within his paper entitled "Parametricism as a style: parametricism manifesto", the dogmas were basically concerned with the principles used in creating forms (interarticulating, hyperdizing, and the uses of splines and NURBS) and using scripts rather than models, while the taboos included the use of platonic objects, straight lines, right angles and, other familiar topologies.
In 2009, he tried to make his principles clearer, concentrating on the concept of parametric design in more depth, in "Parametricism: a new global style for architecture & urban design", in which the dogmas were further clarified such that all forms must be parametrically malleable, with forms inflected or correlated systematically and differentiated gradually, while for the taboos, he introduced new principles not previously mentioned (simple repetition and juxtaposition of unrelated systems/elements) and included hermetic forms within the platonic forms noted in his previous paper. Finally, in his book "Autopoiesis of architecture" he repeated the same dogmas and taboos, further emphasising on the process of creating forms and related systems within the process, and using the phrase "rigid geometric primitives" for taboos rather than platonic or hermetic forms.
This paper adopts the final dogmas and taboos as a theoretical framework to apply to the selected case studies according to Table 2:

Table 2. The context of parametricism according to Schumacher principles

Dogmas								
Design process				Shapes				Internationality
Script rather than model	Generative components	Use NURBS & Splines	All parts are paramet rically	Interarticulate	Hyperdize	Morph	Deform	Deterritorialize

Taboos					
Forms				Repetition	
Familiar topologies	Platonic objects	Straight lines / right angles	Juxtaposition of the unrelated elements	Simple repetition	Do not add / subtract without elaborate interarticulations

2.4 Applying the theoretical framework of Schumacher's Taboos and Dogmas to parametric architecture: Case studies.

The case studies in this research were selected to reflect complex buildings, built recently, with the use of parametric design tools throughout different design phases.

2.4.1 The Opus building, Dubai. Completed in 2019

This 20-story building is a hotel with office spaces,12 restaurants, and a rooftop bar. Seven further floors lie belowground. The most distinguished feature in terms of the visual appearance of this building is the "massive irregular void" in the middle of its façade, which offers a sense of a single volume with a smooth transition between the two towers. This free-form structure could not have been

built in the pre-digital era, as its unique geometries highlight that this building is a result of a complicated parametric system, based on parametric design concepts.

Figure 1. a. Front façade, Opus complex building, Dubai; b. interior design. Pictures credit: Laurian Ghinitoiu

The freeform shape in this project was obtained by applying manipulation to a simple object (box), with an undetermined geometric juxtaposition on the simplicity of the overall shape[15].
According to Schumacher principles, this shape is deformed, hyperdized, and morphological, with these principles following his dogmas.
Planar quadrilateral (PQ) meshes were used as an algorithmic input in the process to design the façade parametrically, based on a sophisticated optimisation strategy. This technology permits the representation of the shapes to control panel size to achieve architectural and production requirements [16].

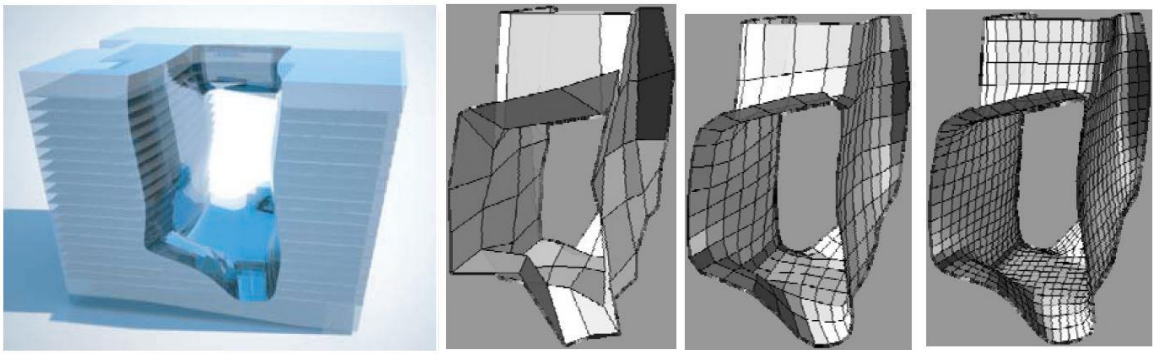

Figure 2. a. The Opus Project model (Zaha Hadid Architects, Dubai); b. PQ meshes of different resolution [16]

2.4.2 Morpheus Hotel, Macau. Completed in 2018

This 40-storey hotel and casino was designed by Zaha Hadid Architects in Macau, China, as a rectangular envelope of 160 m in height. The shape encompasses a series of curved voids that generate

sculptural forms defining the hotel's public spaces, being designed as two separate towers connected by two footbridges.

Figure 3. a) Morpheus Hotel front elevation view. Picture credit: Ivan Dupont
On the left, working with the envelope in the parametric software (Rhino+ Grasshopper)
Upper left showing the complexity of the form[17].

An exoskeleton with approximately 2,500 steel members shapes and supports the façade[17]. Zaha Hadid Architects developed a parametric model in Rhino, along with its plugin Grasshopper, to control the lines of the exoskeleton and coordinate it onto the free- form façade. Significant collaboration occurred between the structural engineer (Buro Happold) and the architects, and several iterations were developed. Two models were then generated for the cladding of the façade: one was used for representation purposes and the other for the structural engineers and the façade contractor[18].
The structural engineer employed parametric design in many ways, including in the generation, documentation, and optimisation of the 2,500 connections of the exoskeleton of the steel structure[17]. Parametric systems were also used on many other levels of this project, from generating the design to the digital fabrication, to automatically generating documentation and gathering the exoskeleton connections and cladding. Textual and visual parametric tools were used throughout the project.
Applying Schumacher principles to the Morpheus hotel, the geometry is complex and differentiated gradually, being deformed with scripting rather than modelling (dogmas). There is no simple repetition, and no rigid geometric primitives exist after the deformation in the free shape process. As most Schumacher principles are realised, this project lies within parametric architecture.

2.4.3 Lovuvre, Abu Dhabi (LAD), 2017

This project is an example of the use of parametric design in the main part of it. The Louvre museum consists of many pavilions used for exhibitions and activities. with a huge circular dome of 180 meters in diameter covering these pavilions. The dome consists of eight layers: four stainless steel clad layers on the outside, while the others, clad with aluminium, are on the inside, separated by a five metres of steel frame.

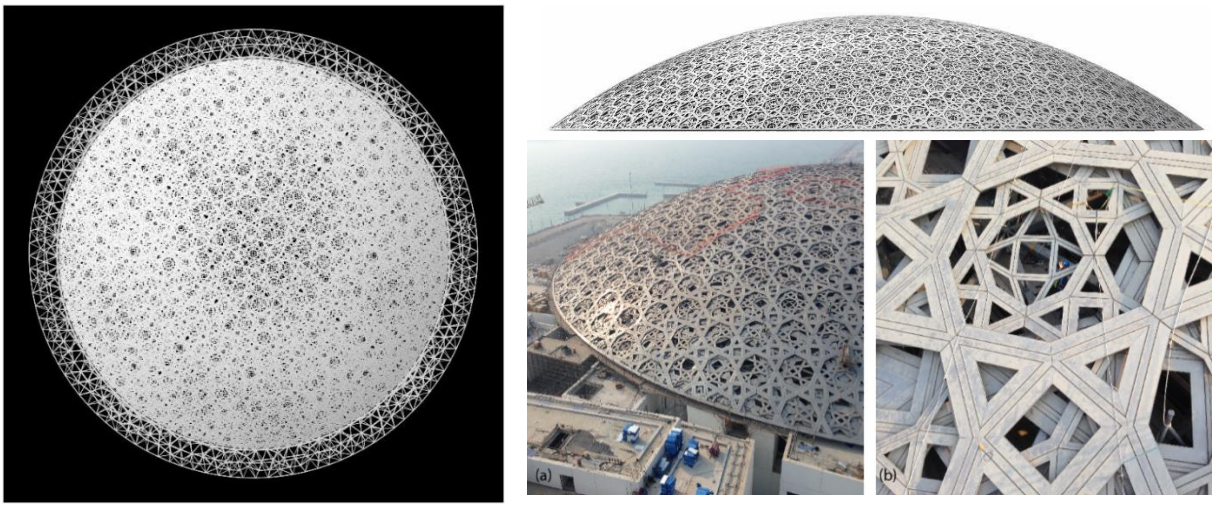

Figure 4. Dome of the Louvre pavilions in Abu Dhabi, 2015 designed by Jean Nouvel [19]

Highly geometric design studies were used to achieve the dome's complex pattern, and for all eight layers, the pattern is repeated at various sizes and angles, as shown in Figure 4. The basic geometries for the pattern originated from a single element, a filigree web tessellation.

A shared parametric model was used for design optimisation and fabrication using Digital Project software and SVN, a web-based model repository. Collaboration between architects, structural engineers, and consultants on the dome model took place using Gehry technologies, which allowed all participants to work simultaneously on different problems within the same model [20].

The system used in the LAD project and other parametrically based design projects provides an approach for easier distribution of models, studies, thoughts and information in a collaborative environment by following a parametric workflow that enhances problem solving throughout the various phases of the design.

Overall, the project featured complex geometry and followed a parametric design approach to achieve the final results, with no simple repetition; all systems were also parametrically connected.

2.4.4 Aviva Stadium, Dublin 2010

The Aviva Stadium, shown in figure 5, was the first project to be designed using commercial parametric modelling software throughout the process from the beginning of the project to the final product design. A single model, produced in Benetly's Generative Components (GC) was distributed and shared between the architects and engineers to facilitate optimisation of design form, structure and facade based on simplified dynamic design discussions and conversations, including exchanges of ideas between multiple parties[21]. Scripting was employed, along with other input parameters, to achieve the envelope of the building, with the façade system and cladding added later.

Examining the Aviva stadium design approach, the parametric design concept was used as a communication tool, for decision-making, and as an approach to determining suitable structures and relevant construction details.

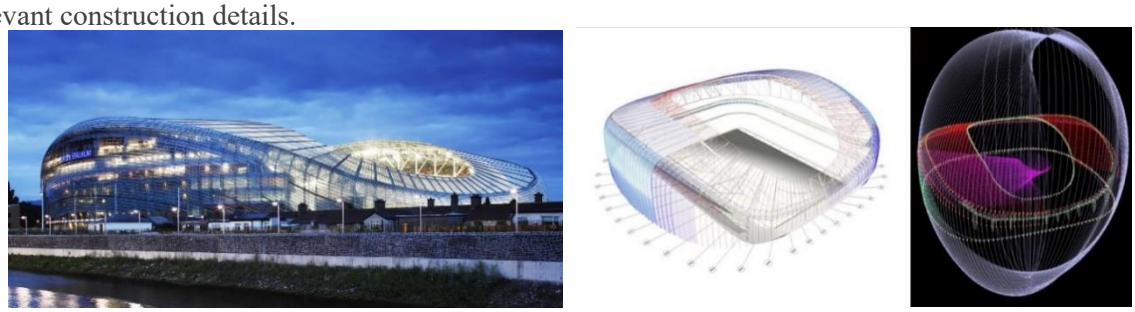

Figure 5. Aviva Stadium, Dublin 2010

Table 3. Applying the theoretical framework of Schumacher's Taboos and Dogmas to parametric architecture case studies

Dogmas									
	Design process				Shapes				Internationality
	Script rather than model	Generative components	Use NURBS & Splines	All parts are parametrically	Interarticulate	Hyperdize	Morph	Deform	Deterritorialize
The opus building	✓	✓	✓	✓	✓	✓	✓	✓	✓
Morpheus Hotel	✓	✓	✓						✓
Lovuvre Abu Dhabi	✓	✓		✓	✓				✓
Aviva Stadium		✓	✓	✓					✓

Taboos						
	Forms				Repetition	
	Familiar topologies	Platonic objects	Straight lines / right angles	Juxtaposition of the unrelated elements	Simple repetition	Do not add / subtract without elaborate interarticulations
The opus building						
Morpheus Hotel						
Lovuvre Abu Dhabi	✓					
Aviva Stadium					✓	

✓ Achieved

2.5 Analysis Conclusion

Analysis of the case studies shows that in all four cases, the use of parametric design was employed at different levels, starting from the initial idea and continuing to the final design product, including the construction phase, and the role of parametric technologies included supporting collaboration between the designers and other engineering disciplines. There were no clear and common characteristics or features, despite several similarities in general aspects, especially with regard to the concept of rejection. In case studies 1 and 2 (The Opus building and Morpheus hotel), the designs were adapted

from known shapes or forms, which were then manipulated and deformed into hyperdized or hybrid forms by cutting part of the façade in a sudden unusual way to create voids. In these two cases, most of the principles in the Dogmas were thus observed regarding the shape and the design process, with deformation, the use of NURBS and splines, and incorporation of generative components in the design of the panels and the façade elements. With regard to the Taboos, there were no straight lines, no familiar topologies, and no simple repetition; indeed, some of the components were manufactured in such a way that they were unique and thus impossible to replace or copy for use in another place within the same project. In the LAD project, scripting was used rather than modelling for the pattern of the dome, with all the dome layers formed of generative components. The concepts underlying such patterns have spread widely within the last few decades, and this complex pattern is thus deterritorialized. With regard to Taboos, the main project form, the dome, is a familiar topology; however, in a break with the past, the complex pattern reshapes it, and there are clearly no straight lines or right angles and no simple repetition, as the pattern is complex and reproduced at different sizes and with rotated angles. Finally, for the Aviva stadium, the envelope of the building was based on scripting rather than modelling, with clear use of splines and NURBS, as shown in **Table 3.** the shape was not deformed, however; instead, parametric technology was used to control the façade and panels rather than shaping a unique project, while in terms of taboos, simple repetition was not avoided. Overall, parametric principles were realised in most of the selected case studies.

3. International style in architecture

The use of the word "style", as with many phrases related to architecture, is controversial, and it has accreted numerous meanings over time. The word can be traced to the early 14th century, with the word "stile" referring to a manner or way of life, including behaviour and mood of expression, from the old French *estile*, derived from the Latin *stilus*. From 1814, the word meaning tended to "mode of dress" [22].

In architectural terms, style is defined in the Illustrated Dictionary of Architecture as the general appearance of the architecture of a building, including its form, construction and ornamentation, which refer to distinctive individual expression or be part of a wider cultural pattern [23]. Style is thus basically related to the appearance of the building and has no connection to its function, being concerned almost exclusively with the visual features of the buildings [24]. Based on this, this visual approach to style is adopted in this paper.

Historically, three key features of International Style were recognized by Henry-Russell Hitchcock and Philip Johnson in a book printed to accompany the International Exhibition of Modern Architecture, held in 1932 at New York's Museum of Modern Art: abstraction of applied elements; dynamic balance rather than mandatory symmetry; and the statement of volume rather than mass [11]. International style was thus fundamentally modernist, known by its pure lines and lack of ornament, being built from steel, glass, and other materials of the machine age. Practically, the international style was not more suitable for one climate over another, being implemented in Finland as readily as in Mexico or California. Moreover, several European architects such as Mies, Gropius, and Breuer supported the spread of the style through America, while other architects played similar roles in different parts of the world [25].

International style differs from the concept of style in its conventional domain; the most important principle of international style in modern architecture was originality, which represents the main aspect of modernity within scientific rationalism; Schulz confirmed that "the principle of modernity is that architecture be innovative, as if there was nothing before it at all". Similarly, Reyner Banham indicated that forms and shapes from many different trends found a home within modernity, making it difficult to obtain common properties; however, all of these had common general aspects which distinguished them from architecture in the period before 1900 [26]. The international style thus represented the most expressive trends of modern architecture in terms of the prevalence of concept and repetition of characteristics.

The principles of the international style realised in modern architecture included:

- A dependence on repeated functional determinants and standards, generating predetermined and targeted models and solutions.
- A move away from moral content resulting from a disconnection with the past and the use of abstraction, with objectivity as a basis.
- Achieving parity through repetition, building identical homes by relying on repeating the same executive plans to generate equivalent homes.

4. Discussion

Parametric architecture as a style does not fit within the traditional understanding of styles, but rather encompasses a concept that aligns it with the international style developed in modernity. Parametricism, as the heir to post-modernism and deconstruction, was preceded by many trends and thoughts in architecture, one of which was the rejection idea [27], Jencks, in "The architecture of the jumping universe", examined the need for new architecture to represent the cosmic meanings emerging in the new worldview and the realities represented by sudden developments. This can be done by linking architecture with the science of complexity and cognitive sciences. However, Zaha Hadid rejected the concept of gravity when producing her floating architecture, and the rejection concept in parametric architecture was expanded to reject architectural history and even the idea of international style, rejecting that which preceded it. Based on this, a comparison between the two styles emerges:

1. The International style in modernism and parametric architecture did not emerge from any architectural thought based on the idea of style; instead, each of them was preceded by diverse architectural movements, with the concept of the style launched later. Modernism can be seen developing in the writings of Henry-Russell Hitchcock and Philip Johnson, while parametric architecture emerges most prominently in Schumacher's publications, which announce the emergence of the new style in architecture.
2. The main concept underling both styles is originality and innovation, as the design products of both do not combine clear and distinctive characteristics within their models; instead, what those models share is innovation and originality, being unique from that which preceded them. In modern architecture, all historical styles were refused, while for parametric architecture, all that preceded it is rejected, including modern architecture.
3. The general principle for the International style in modernity is the principle of rejection; this includes rejecting symmetry, rejecting ornament and rejecting mass in favor of volumes, while in parametric architecture, many principles were coined by Schumacher as "Taboos" to be avoided and rejected, such as familiar topologies, platonic objects, straight lines, right angles, simple repetition, and addition or subtraction without elaborate interarticulation.
4. In International style within modern architecture, the forms and products shared common features at the level of principles, the repetition of solutions, and duplicated forms, materials, and visual characteristics that entitled it to the term "functional architecture", based on the products of the machine age, while parametric architecture within Parametricism shares common principles among forms and products as a result to the use of programming in design, a product of the digital age. Numerous software types have thus developed in support of the design process, offering a wide range of solutions to inform production or construction. Similarities in structural and construction solutions are thus derived from the similarities and widespread use of design and implementation methods.
5. The concept of repetition is prevalent in both styles, based on the similar functional solutions in modern architecture and the increasing number of parametrically generated images with complex and fluid forms within recent architectural practice and even in architectural education.

No.	General principles of Style	Common features between the two styles	International style	Parametric architecture
1	The emergence of the idea and its development into a “style”	The two styles emerged from architectural thought based in in renewal and revolutionary movements and not in conventional ideas of style.	Based in modernism, it emerged in various architectural movements with their different trend, mainly in the writings of Henry-Russell Hitchcock and Philip Johnson	Parametric architecture as a style emerged from different architectural trends, beginning at the end of the twentieth century, being defined most clearly in Schumacher publications, where he described it as the new style in architecture
2	Originality and innovation	The design products in both styles do not combine clear and distinctive characteristics within their models; instead, models share innovation and originality, or are unique in terms of what has preceded them	In modern architecture, all historical styles are refused	All that preceded parametric architecture is rejected, including modern architecture.
3	The principle of rejection	The general principle for both styles is the principle of rejection.	Rejecting symmetry, rejecting ornament and rejecting masses in preference to volumes.	In parametric architecture, many principles were identified by Schumacher as “Taboos” which should be avoided and rejected, such as familiar topologies, platonic objects, straight lines, right angles, simple repetition and the addition or subtraction without elaborate interarticulation.

4	The concept of repetition	Both share the principle of repetition, emphasising formulations of the same technical solutions and scientific standards in relation to form production	Forms and products share common features within modern architecture at the level of principles through the repetition of functional solutions and duplicated forms, materials and visual characteristics to generate a “functional architecture” of the machine age.	Forms and products also share common principles as a result to the use of programming in design within the digital age. Numerous software programs have been developed in support of the design process, offering a wide range of solutions to both form production and construction, utilising the repetition of solutions as coined in Schumacher’s principles and implementing methods in response to the complexity of contemporary architecture .
5	Links with contemporary technologies and sciences	Both share principles with their temporal period	The international style was associated with the emergence of modern construction techniques and methods that appeared with the industrial revolution at the end of the nineteenth century and spread at the beginning of the twentieth century, including the emergence of the principles of standardisation, mass production, and similar solutions that deal with architecture as an objective industry, matching the character of the era	Parametric architecture and its implementation have been linked to the technology era, the information revolution, and the complex sciences based on the avant-garde geometries that appeared parallel to its spread

5. Conclusion

This investigation makes it possible to conclude that whenever architectural movements introduce theories of rejection and elimination of the dominant architectural language, they by necessity reach a stage in which they must seek new language; thus, contemporary architecture is still in the process of trying to settle on a new language to use for the parametric architecture productions which have begun

to present themselves within the new international style as part of the process of formation and presence of global space with regard to capacity. Within this domain, parametric architecture can be defined as a second international architectural style whose features are not yet completely formulated; nevertheless, it has many convergences with and analogies to the mechanisms that supported the emergence of the International style in modern architecture. This differed from the concepts of previous international styles based on its historical context, which defined it as a set of elements, vocabulary and architectural characteristics repeated in a specific time and place. The new International style was thus based on the principle of rejection of and revolution against prevailing architectural norms or the formal characteristics associated with them in pursuit of novelty and innovation and the creation of that which was original and unprecedented; similarly, the products of parametric architecture examined in this research share with each other greater avoidance and refusal of features (Taboos) than subscription to requirements (Dogmas).

A comparison of parametric architecture with the International style thus shows the participation of both styles in several general theoretical principles, the most important of which is the principle of rejection and the search for the new; this refers particularly to the rejection by each of the formal or formative characteristics prevalent in previous styles, represented by the rejection of symmetry and the rejection of masses in the international style and the rejection of the Taboos in parametric architecture. Although the principle of rejection does not necessitate participation in or affirmation of positive characteristics, the new product inevitably acquires a kind of participation, whether in general theoretical principles or formal characteristics, due to the technologies required to produce the form imposing on the design and the implementation of repetition resulting in products with the same standards or which meet the same demands. This is represented in the International style by repeating functional solutions, repeating forms and standardisation, as well as by repeating the same models within standardised buildings or prefabricated constructions, while in parametric architecture, it is represented in the process of design and implementation of complexity.

Based on this, parametric architecture can be presented as an international style, which the language of contemporary digital architecture can be seen to be dependent on, despite its complexities and potential fragmentation in multiple directions.

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