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Toward the formulation of a proposed frame for the formal and structural specifications of the modern parametric digital architecture

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Abstract

Background: This research paper contributes to presenting a proposed framework for the formal and structural specifications of parametric digital architecture in order to increase knowledge and know-how in this field closely to specialists and those interested in it through the research methodology, which is divided first into the theoretical background to include a presentation of the definition of digital architecture and the most important pioneers of digital architecture, digital building materials and construction mechanisms parametric digital and what are the most important computer software used in parametric digital architecture in terms of design and construction implementation and identifying the most important digital specifications and characteristics that were mentioned in previous studies in this field and what are the unconventional digital esthetic values, then comes the role of the applied study in formulating a comprehensive matrix of parametric design modern and its impact on the development of traditional architectural models in digital architecture.

Results: The research study found that both (unrealistic shape) and (typical interaction) ranked first with the highest percentage reaching 100% in all study cases. The ratio of the volume of each to the total volume of all elements of morphological characteristics and non-traditional esthetic values was 8%, the most important characteristic of buildings in parametric digital architecture, in most of them, is the lack of realism to a very significant degree, and we always find a clear increase in the interaction, vitality and dynamism of buildings with the surrounding environment.

Conclusions: The most important characteristic of buildings in parametric digital architecture, in most of them, is the lack of realism to a very significant degree, and we always find a clear increase in the interaction, vitality and dynamism of buildings with the surrounding environment. While we conclude that the least characteristic of the parametric digital buildings is the simulation of nature or the tendency to everything that is traditional, as well it is often inclined to everything strange and unfamiliar.

Keywords: Digital architecture, Parametric model, Parametric design, Digital building materials, Digital architecture software, Formal characteristics and aesthetic values of digital architecture

1 Background

The digital revolution was reflected in architecture like the rest of the scientific, life and social fields, so its impact was evident in the architectural formation. The architectural product became not limited to the design

by the usual traditional methods and then drawing it by the computer but went beyond that. The produced shapes became the product of an intellectual design process that is directly affected by digital media in general. Digital shapes can be considered as based in their design and implementation entirely on the use of the digital language of the computer by using parametric design software. These programs have provided architects and designers with huge mathematical operations that used

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to take months and years, as the more the degree of complexity of architectural block is, the more complex the calculations and intertwining, and the more difficult it is to implement it on the ground by the constructors and contractors. All these difficulties limited creativity in design and made the architectural blocks simple and easy to implement, but with the emergence of a new generation of architects interacting and coping with this new thinking. This new path must be clarified for architecture in an attempt to formulate it in a clear and sequential manner, for easy understanding and work with it within the trends of sustainable digital architecture that has become a necessity.

1.1 Research problem

The problem of the research is the absence of clear boundaries and typical standard methodology around the diverse and multiple aspects of parametric modeling that digital architecture is currently adopting in the design and implementation of many projects that fall within the tasks and specialization of the architect. There is also a clear lack of knowledge in this field at the academic or professional level, especially in societies that are new to digital architecture.

1.2 Research objectives

1. Accessing a matrix that includes contemporary architectural ideas emanating from the digital revolution in architecture and defining its philosophical thought.
2. Defining the modern parametric design methodology used in our present time to develop architectural formation models in digital architecture.
3. Drafting a clear framework of knowledge about the field of parametric digital architecture.

2 Methods

Accordingly, the main goal of the research was to address the topic and field of digital architecture and parametric design in a systematic and structured framework. This would briefly include the most important aspects in this field, including the definition of digital architecture and knowing the most important pioneers of digital architecture. In addition to the principles of digital architecture, what is meant by parametric design, its importance, what is meant by the parametric model, its creation and its importance. It also includes the impact of the digital revolution on architectural thought and what are the digital building materials and parametric implementation mechanisms and what are the most important computer software

used in digital parametric architecture in terms of design and implementation. We will also realize, through that framework, the digital specifications and formal characteristics that were mentioned in previous studies in this field and what are the non-traditional digital esthetic values.

3 Theoretical background of the research

3.1 Definition of parametric digital architecture

It is the architecture that uses information technologies to control its parts and operate its various functions and produces its designs due to the reliance on information systems in the various activities of life, which may change in its various aspects, whether in form, function or construction, and this is the new and independent aspect of digital information architecture., where it was able to integrate all the architectural elements and turn them into determinants or logarithmic elements that are easy to transform and form [1].

3.2 Characteristics of the forms of digital architecture

The new forms in contemporary digital architecture seem to be moving, unstable, broken, fluid, twisting with morphological and topographic characteristics, their space overlaps each other, and they have no specific masses. Parametric to draw inspiration from natural organic forms inspired by natural forms such as water, clouds, plants, animals, space and the universe [2].

Parametric design represents the medium that strongly influences the emergence and emergence of new methods of digital design in a wide range of fields of architectural, industrial and fashion design, as the parametric design not only affects the formal characteristics of modern designs, but also produces a new model for design thinking. The most important features of parametric digital design can be identified. As follows [3, 4]:

- Generate and explore multiple design alternatives.
- Flexibility and adaptability.
- The possibility of using parametric design in different stages of the design and construction process.
- The application of parametric modeling in various design standards such as architectural and urban design, interior design and furniture design.
- Representation and modeling of complex geometry.
- The participation of many disciplines in the parametric design process.
- The role of parametric design in modeling building data and information using specialized computer software.

3.3 What is the parametric model?

The term parameter is used in a variety of disciplines such as mathematics and digital architectural design, as the parameter represents a measurable factor that defines the system or defines its limits. Surveying and redrawing any of its geometric components, mathematicians were able to reach and understand non-traditional shapes, and these shapes have different properties from the traditional shapes that he called topological shapes [5].

3.4 Importance of creating a parametric model

The parametric model is the backbone of the parametric design process, where the process of creating the parametric model is an important stage in the digital design process in general and in the parametric design process in particular, because at this stage designers put the variables and the digital data flow and adjust the parameter values and revise the rules accordingly. From the traditional methods of formation and formation of the entity itself, the design of the generative set of rules and their logical relationship has become the main focus of design thinking. The following lists the reasons for its importance:

- Using parametric models makes changes in the design entity easier, as the parametric model allows the designer to make changes and reconfigure the geometry without erasing and redrawing.
- It helps in exploring and evaluating multiple design alternatives according to various criteria and choosing the best solutions for designing and creating parametric architectural models, as it has a level of flexibility that allows it to be constantly updated when adding, changing or deleting one of the components within the structure of the parametric model.
- Parametric modeling made it possible to shorten and rationalize the design time of buildings using traditional methods and to develop building solutions using a rational, prior and integrated logical basis.
- The ability to interact and respond to the variables imposed by the designed environment or according to the designer's desire, as it is characterized by the expansion of design exploration in the early stages of the design process. It also provides flexibility to design parts and assemblies of a complex nature and provides reliable systems for testing various design cases resulting from a single model [6].

3.5 How to create the parametric model

By using the parametric design in creating the parametric model using the computer, where the primary elements

that are formed with each other are referred to using a number of clearly defined variables and constraints. Thus, the completed parametric model can be changed, modified and re-generated within the limits of conformity to the pre-set conditions. The model parametric can be updated by changing the parameter values while preserving the relationships between its components. The design and construction of the parametric model passes through important stages from the beginning of the design process to the stage of developing ideas for the external configuration of the building as well as the stage of interior design [7].

3.6 Pioneers of digital architecture [8]

The seventies of the last century witnessed the emergence of many pioneers of parametric digital architecture, who left their clear imprints and distinguished and pioneering architectural works in this field, and the following is a list of some of these architects:

- Marcos Novak
- Stephen Perella
- Cass Austris
- Knox Notre Dame
- Patrick Schumacher
- Frank Gehry
- Norman Foster
- Frey Otto
- Jamal Bakri
- Hani Rashid
- Tariq Naja
- Ali Rahim
- Zaha Hadid

3.7 Computer software used in the parametric design

The continuous development and renewal of specialized engineering parametric design programs enables users and designers to work with the parameters of new standard geometric shapes. Here is a list to display the most important ones (Table 1).

3.8 Methods of implementing buildings in parametric digital architecture (the computer as an implementation tool)

Parametric digital architecture uses computer-managed manufacturing machines to implement its buildings to ensure the speed and accuracy of production as follows:

3.8.1 Digital implementation method using 3D printing

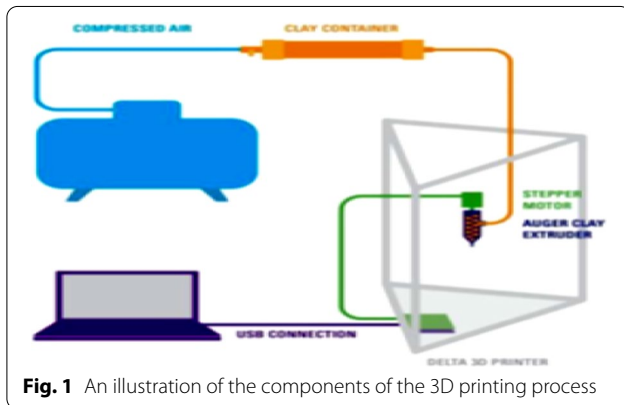
3D printing is one of the addition manufacturing techniques, where pieces are manufactured by dividing 3D designs into small layers using computer programs

Table 1 Parametric design programs

The program	Description
1. Generative Components Program [9]	Bentley's Generative Components program is a parametric CAD program, it was developed in 2003, According to Aish, the Generative Components program is a parametric design tool that creates design rules that search for alternative solutions represented in multiple geometrical (complex) graphics associated with it. The program tries to give three-dimensional modeling capabilities to solid forms of architectural design by providing more diversification in them. The program is mainly used by designers and workers working on geometrical shapes in the design of buildings. The program supports many file extensions to interact with programs such as Rhino and AutoCAD. The program uses a simple coding language that allows creating custom programs (according to the user's desires). The parametric design created in this program is characterized by that each element of the 3D model can be constructed according to its relationship to the other element, and numerical values can be changed at any time. Mathematical formulas for commands can be accessed in place of standard commands such as copying or repeating operations performed by a series of mathematical operations. The program is also characterized by the presence of multiple methods of defining and monitoring the parametric correlations between the elements of the model in a responsive and workable environment throughout the design process. Parametric correlations are characterized by flexibility in controlling the design elements
2. Rhinoceros Program [10]	It is a programming environment from Rhino Script that was developed by Mc Neel, it is an easy and integrated method using 3D modeling and represents a well-known application and is used by many designers and architects, and it is based on the Visual Basic programming language. It works with NURBS objects, and it has potential for collaboration between different environments
3. Digital Project (CATIA) [11]	It is a computer-aided parametric design program developed by Gehry Technologies based on CATIA V5, The program uses the Visual Basic programming language and allows the user to develop additional applications, symbols, entities and shapes and at the same time allows the user to calculate the estimated budget and use of materials. The program provides well-designed tools for users to design components and assemble them into multiple (complex) formulations, as well as it allows the user to define the detail components it designed. Users can perform calculations and analysis on the model, and the program can be used interactively with programs such as AutoCAD
4. BIM Revit [12]	It represents the Building Information Modeling System (BIM), It was developed in response to the need for software that can create three-dimensional parametric models that include both the geometric shape, geometric shape design and building information. It allows users to design the building, structure and its components in a 3D model. Modeling tools can be used with pre-made solid objects or imported geometric models. The program lacks the ability to handle NURBS entity and single polygon entity except for some specific entity types such as trellises, terrain or bulk environment. The software assists with collaboration between teams and ensures that all information (floors, schedules, etc.) is updated whenever any changes are made to the model. It also assists to access construction information from the construction model database. Every change made to an element in the Revit is automatically published through the form to maintain the consistency of all the components of the Views, and the program has the ability to plan and track different stages in the building life cycle from idea to construction, subsequent maintenance and / or demolition, and Revit adopts programming language Python & Visual Basic
5. Dynamo [13]	It is described as a tool that allows parametric design in the context of a BIM project, it represents a flexible and scalable tool because it can work as a standalone application or as an addition to other design programs, as it can work as an add-on for both Vasarl & Autodesk Revit. It represents the visual programming tool that aims to be in the reach of both non-programmers and programmers alike, with the ability to use various scripting languages, and the ability to formulate the way in which data is processed (numbers or texts). The graph and the results of the 3D drawing are displayed both in the workspace
6. 3DS Max UI. [14]	It is a parametric 3D modeling program that supports visual programming and provides modeling, animation, simulation and rendering functions for games, movies and animation. It uses the concept of wire ratios and parameters to control the geometry and gives the user the ability to write its Max Creation Graph. It is based on the Maxscript programming language and has limited support for NURBS
7. Inventor [15]	It is a Parametric 3D drawing and modeling program based on extruding, rotating, drawing of basic surfaces. It is a first-rate mechanical 3D modeling software known as manufacturing and production software specifically. The program shows all the work sequentially within the browser, unlike AutoCAD, which hides the work parameters and design results
8. Marionette [16]	It is a visual programming environment for architectural, engineering, construction, outdoor spaces and industrial design. It enables designers to create custom application algorithms (as per user desires) that build interactive parametric entities and simplify complex workflows, as well as build automated 2D drawing, 3D modeling and BIM workflows within Vectorworks software. It was created according to the programming language Phython
9. Maya [17]	This software was developed for the film industry (primarily for animation) and has been used in recent times by many architects in the conceptual design stage, This design approach requires programming or scripting knowledge and is inherent in mathematical algorithms where interactive design is not possible

Table 1 (continued)

The program	Description
10. Modelur [18]	It is a parametric 3D software that is used to design Urban areas, as a plugin for Trimble Sketch Up. Its primary goal is to help users create conceptual urban clusters. It provides the design of the built environment through major urban parameters such as the number of floors and the total land area of the building, and it also calculates the main urban control parameters (such as the floor area ratio or the required number of parking spaces). It helps to make an informed decision during the early stages when design decisions have the most impact

**Fig. 1** An illustration of the components of the 3D printing process

and then they are manufactured using 3D printers by printing one layer above the other until the final shape is formed. This system differs from the two Milling molding and sculpting systems, which waste more than 90% of the material used in manufacturing. 3D printers provide developers with the ability to print interlocking parts with complex installation. Parts can be made from different materials with different mechanical and physical specifications and then combined with each other. 3D printing technology is used to build product parts or the first model in the form of layers, where the required part is drawn with the help of a modeling program and then divides the design into (Algorithm Draw) so that each shape turns into digital data. The printing device then implements it in stereoscopic from the material selected with fine details for each layer, as in Fig. 1. Each layer is constructed by pressing a connected rope of clay over the surface of another layer of clay that was prepared as a basis [1].

3D printing advantages:

- Easy to modify design.
- The possibility of obtaining large parts, protruding parts, overlapping parts, dovetail parts with an angle of less than 90 degrees.
- An integrated recovery system for raw materials, through the recycling of raw materials.
- Use not many tools or devices, to save time and cost.

- There are no limits to the complexity of the design, it is possible to implement the form, regardless of its details.
- Less cost, as it is possible to depend on one person in designing and implementing, and also the possibility of implementation anywhere.
- A short production cycles.
- Obtaining a product that conforms to all standard specifications, not from the old traditional methods that are filled of defects in forming and manufacturing, whether by manual formation, or excesses that occur as a result of the casting process.

3.8.2 Different 3D printing methods [19]

1. Atomic diffusion additive manufacturing (ADAM) is the latest end-to-end process of industrial 3D print manufacturing, conceived by Markforged to solidify strong metal 3D components. It works by encasing metal powder in plastic and then printing the component one layer at a time. The layers are just 0.05-mm-thick. After the printing has finished, the part is washed and then moved to a furnace that burns away the plastic and sinters the metal powder together to create a strong end-use metal part.
2. Stereolithography (SLA) is the original industrial 3D printing process. SLA printers excels at producing parts with high levels of detail, smooth surface finishes and tight tolerances. The quality surface finishes on SLA parts, not only look nice, but can aid in the part's function—testing the fit of an assembly.
3. Selective laser sintering (SLS) melts together nylon-based powders into solid plastic. Since SLS parts are made from real thermoplastic material, they are durable, suitable for functional testing, and can support living hinges and snap-fits. In comparison to SL, parts are stronger, but have rougher surface finishes. SLS doesn't require support structures, so the whole build platform can be utilized to nest multiple parts into a single build.
4. Digital light processing (DLP)

is similar to SLA in that it cures liquid resin using light. The primary difference between the two technologies is that DLP uses a digital light projector screen whereas SLA uses a UV laser. This means DLP 3D printers can image an entire layer of the build all at once, resulting in faster build speeds. While frequently used for rapid prototyping, the higher throughput of DLP printing makes it suitable for low-volume production runs of plastic parts.

5. PolyJet

is another plastic 3D printing process, but there's a twist. It can fabricate parts with multiple properties such as colors and materials. Designers can leverage the technology for prototyping elastomeric or over-molded parts.

6. Multi jet fusion (MJF)

builds functional parts from nylon powder. Rather than using a laser to sinter the powder, MJF uses an inkjet array to apply fusing agents to the bed of nylon powder. Then a heating element passes over the bed to fuse each layer. This results in more consistent mechanical properties compared to SLS as well as improved surface finish. Another benefit of the MJF process is the accelerated build time, which leads to lower production costs.

7. Fused deposition modeling (FDM)

is a common desktop 3D printing technology for plastic parts. An FDM printer functions by extruding a plastic filament layer-by-layer onto the build platform. It's a cost-effective and quick method for producing physical models.

8. Direct metal laser sintering (DMLS)

metal 3D printing opens up new possibilities for metal part design. The process we use at Protolabs to 3D print metal parts that is direct metal laser sintering (DMLS). It's often used to reduce metal, multi-part assemblies into a single component or light-weight parts with internal channels or hollowed out features. DMLS is viable for both prototyping and production since parts are as dense as those produced with traditional metal manufacturing methods like machining or casting. Creating metal components with complex geometries also makes it suitable for medical applications where a part design must mimic an organic structure.

9. Electron beam melting (EBM)

Electron beam melting is another metal 3D printing technology that uses an electron beam that's controlled by electromagnetic coils to melt the metal powder. The printing bed is heated up and in vacuum conditions during the build. The temperature that the material is heated to is determined by the material in use.

3.8.3 Digital implementation method using reverse engineering [1]

Reverse engineering is useful for duplicating an existing element, modifying its design, or other uses, and this is done by scanning this element, whether it is 2D or 3D.

- 2D scanning

Two-dimensional images are scanned and converted into 3D drawings that can be used in many applications and export these drawings to rapid prototyping machines or to carving, milling and cutting machines. There are some programs that convert these images into 3D models by programs such as Art Cam Pro.

- 3D scanning

There are several methods of 3D scanning, including:

1. Digitizing: This method relies on touching or passing a sensor or a special pen on a number of points of the model for which a three-dimensional scan is to be scanned with a precision of up to 0.01 mm. The scan results in three-dimensional digital files as shown in Fig. 2.
2. Optical scanning: This type of three-dimensional scanning depends on special cameras, and these cameras can make three-dimensional models in true colors, and they can scan models up to a height of 7.6 m, as in Fig. 3.
3. Laser scanning: These scanners rely on laser beams in three-dimensional scanning with sizes ranging from microscopic objects to an entire building. The accuracy of this method reaches 0.008 mm, noting that the greater the size of the object that the scanner raises, the lower the accuracy. Some architects depend on this method in completing their buildings, including Frank Gehry, as he starts the design with a block model of wood, for example, and then makes a 3D scan of the model, which results in a digital model that is developed and modified using 3D modeling



Fig. 2 Digitizing



Fig. 3 Optical scanning



Fig. 4 Laser scanning

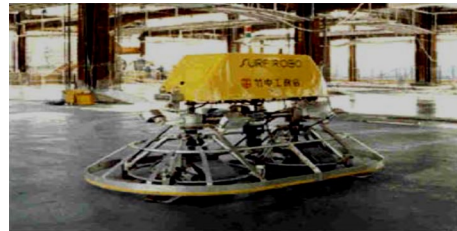


Fig. 5 The robot dedicated to digital construction

programs and from which it is possible to obtain the different projections of the building as in Fig. 4.

3.8.4 Digital implementation method using construction robots

The robot is a multi-purpose digital control programmable handling device designed to move materials and tools used through multiple programmed motions. The shortage of skilled workers is one of the most important factors that led to the development of robotic devices with specific tasks to fill the shortage in skilled labor. These Robots works in construction, finishing floors, painting external walls, quality control, handling loads, building with bricks or blocks, welding, connecting various elements, cleaning and iron painting for isolation painting interior walls, flooring, steel reinforcement and concrete handling, four of these applications are the following:

- The concrete floor finishing robot: It is used in cleaning the concrete surface for areas from 500 to 600 square meters with few obstacles such as columns, walls or openings in ceilings, with the quality of con-

crete parallel or better than skilled labor, and at a speed greater than 3 to 8 times of workers that do the same work manually.

- Spray painting robot: It is often used for painting exterior walls and contributes to reducing work that is dangerous to workers' lives, in addition to improving productivity and raising quality, as it is 2–8 times faster than skilled manual labor.
- Tile inspection robot: It is useful in tall buildings that are clad with ceramic tiles, like in Japan, where the quality of tile installation is of particular importance in terms of extending the life of buildings and preventing these tiles from falling on pedestrians, automatic control of the robot's flow, data collection and display in graphic form that reduces the need to build wrenches as shown in Fig. 5.
- Material handing robot: It is used in internal works that require heavy effort, such as heavy and large-sized materials that workers cannot carry, such as internal panicles, because the use of cranes and heavy lifting machines is not practical inside. There are different types of robots designed to handle and install internal prefabricated walls and to install indoor suspended ceiling panicles, in addition to material

handling in order to reduce hard work on labor and increasing productivity.

3.8.5 Digital implementation method using automatic construction control

They are factory-like systems that can execute entire buildings in record time. There are two types, fixed on site systems and mobile systems. Construction automatic control systems consist of four basic components:

- An integrated system for planning construction operations to carry out simulations and design various details and connections.
- Automated factory for the manufacture of building components.
- A mobile factory that automatically controls the assembly of prefabricated building components.
- A tracking system to ensure that materials arrive at the site on time.

The 34-storey building of Mitsubishi Heavy Industries in Yokohama, Japan, is the highest building that has been built using automatic control technology. There are many integrated building systems, some of which are for metal buildings and others for concrete buildings, and most of them aim to reduce construction time, reduce workers, reduce construction waste, creating a clean, safe and quiet work environment, reducing risky works, in addition to improving and controlling quality. However, the use of this technology is still in a limited range, as it still needs a lot of development to become popular. The new concept is based on providing any moving equipment with artificial intelligence technology, which works to avoid the possibility of collision in the surrounding area that contains various mobile equipment and fixed hurdles. This is done through a number of data on the site, speed, weights, winds and other constants and variables on the site. The system is also equipped with a radar device that allows the ability to identify the area of hazards around it from other equipment and fixed obstacles, and thus, the system works to take all correct measures through the automatic control device for the building to avoid any collision [1].

4 The applied research study

4.1 Previous studies that dealt with the formal specifications of parametric digital architecture

4.1.1 2003 WAN-PING GAO study [20]

The study includes they surveys that have been conducted and dealt with the analysis and defining the formal specifications of the digital architecture, the most

famous of which is the Kao study 2003, where the study concerned with digital forms as this included the most important characteristics of the digital form as follows:

1. The expressive stage of the form
It means the possibility of observing the foundations of the shape, its frame and its core, meaning that the shapes do not express the final stable form, but rather the group of stages through which the formation passes, thus allowing the viewer to be able to imagine the formal foundations, and this is one of the methods of formal maneuver.
2. Stage of the construction frames
The emergence of the structural frames on the outer surface of the figure, where a clear contour of the structural system and the structural components of the building is observed so that they are clearly and explicitly visible to the viewer without the need to hide them.
3. Shape closure
The shape is characterized by a closed total encapsulation of the building, expressing the characteristic of closed space that the human senses and interacts with in a way that enables him to find the appropriate outlet or appropriate mechanism to penetrate this closed structure.
4. Type of surfaces dynamic simulation
The formal properties in this case are represented in simulations of surfaces that can recognize information related to actions, movement, sound and other phenomena of the surrounding environment and respond to changes in shape as a very sensitive method.
5. Form interactivity
The shape is represented in this case by the extent to which the shape interacts with external influences and the fields of force that affect the building.
6. Nonrealistic shape
The shape in this case is characterized by unrealistic shape characteristics represented by inflated air shapes, for example, through a set of advanced morphological changes from the air shapes, and in this case also the possibility of manipulating and maneuvering the shape to cause formal distortions to generate new parametric digital shapes.
7. The type of formal transformation
The feature of digital formation is highlighted and shown through the transformation of the shape by simulation, such as simulating the movement of beach waves, so we find the building formation in general similar to the flow and flexibility of beaches movement.
8. Digital expressive surfaces

The shape in this case is expressed through a sensor wall, which represents an expressive surface that reflects the surrounding environment information on the building's digital sensor wall.

9. Reactive and formal changes

The digital shape of the building can express strong expressions, for example, of the movement of passengers on the elevators through speed, darkness, the range of emotions and the formal changes, which reflects the emotions and human behavior on the building and its formation.

4.1.2 Lars Matthias M. Spuybroek, 2002 [21]

The most important indicators of digital figures from Al-Pujari's study:

1. Unexpected hybrid forms using a genetic algorithm

The importance of using the genetic algorithm in generating and producing unexpected hybrid shapes instead of designing them and exploring surprising new spaces by designers based on computer simulations by developing a model for a virtual digital environment, then adopting the virtual digital genetics of digital architectural forms through computer-aided design by modifying previously stored models and reforming it to generate new shapes and store them in the form of genetic code.

2. Liquid crystal case strategy

The study demonstrates the possibility of adopting a liquid crystal state strategy in generating the digital shape by introducing the forces of the vortex shape into the design process using special software for film making to simulate hurricanes.

3. Abstraction and simulation of nature

The importance of digital technology can be seen in generating architectural forms through the abstraction of nature represented by natural structures and installations, snails and marine crustaceans by adopting the main components of nature.

4.1.3 Wejdan Abdul Jalil 2018 study [22]

The most important indicators of digital shapes from Abdul-Jalil's study:

1. Flying

Raising the building from the ground, so that the ground floor becomes a space for movement for individuals and vehicles, as well as contributes to enhancing free spaces and strengthening communication between the outside (the public area) and the private building spaces.

2. Fragmentation

It is the state of disintegration, loss of coherence and inconsistency in form. Fragmentation in deconstructive architecture has been associated with being a formal design process and an architectural treatment aimed at deconstructing the semantics of architecture as a text with the aim of deferring the meaning and its non-evidentiary.

3. Disassembly

It is the fracturing, asymmetry and incoherence in architecture, and the use of classical architecture concepts in a mirrored or distorted image.

4. Flow

The use of free-form curves, which are characterized by movement and fluidity of contemporary life, is one of the most important characteristics of buildings in digital architecture, as curves help maintain visual clarity.

5. Distortion

The ideas of distortion in digital architecture are the gradual transformation in order to adapt and diversify buildings.

6. Dynamic

The dynamic characteristic is a concept that represents a new thought that adds a new dimension to digital architecture with a dynamic concept, which is time (the fourth dimension and takes a more attentive character to the external environment) and wants to show the enormous potential offered by contemporary digital technology.

7. Breaking the routine

It is characterized by complexity, contradiction, breaking habit and going beyond the familiar, and that beauty may be generated from dissonance as it is generated from consistency, and from chaos as it is generated from order.

A list of the most important non-traditional digital characteristics, attributes and values has been deduced from previous studies as follows in Table 2, and accordingly it will be tested later within the practical study to achieve the goal of the research.

4.2 Study cases

The study case samples that have already been implemented on the ground were selected from the design of the most famous pioneer of parametric digital architecture in the modern era (Zaha Hadid) for practical and applied study in research from the most famous parametric digital buildings, in order to measure the extent to which the elements of the matrix of formal characteristics and esthetic values obtained from previous studies on the following case studies:

1. Regium Waterfront Project in Italy 2007–2015 (Fig. 6)

It is a center for performing arts and a museum with other functions, the idea of the project is based on the formal metaphor of the radial symmetry in star fish, which invested in assembling shapes in a way that facilitates communication between parts of society and that project consists of spaces with various activities surrounding a covered gathering area, and Zaha Hadid intended to show the formal transformation of the design by sculpting the ground floor flowing up toward the sky, making the building appear as if it wanted to liberate from the earth as a plane [23].

2. The National Museum Project (Maxxi, National Museum) in Rome 1999–2009 (Fig. 7)

It’s a museum of the arts of the twenty first century. Zaha Hadid, in the design of this museum, used the protruding block ridges that direct the visitor to the entrance of the project, she designed the building as a huge sculpture which showing the formal transformation of the design by using abstract and complex intertwined with each other, and sloping and dynamic floors not defined by starting or ending point, arched walls and hanging slopes, and the use of a dynamic staircase to connect the five levels of the museum, she achieved the variety and the openness in internal spaces. The building is characterized by high streamlined, which represented the basic organization of the form, which began in the initial drawings of Zaha, which evolved into plans using digital tools, and the architect used unconventional hanging esthetics by creating fragmentation and variety per-

Table 2 List of formal characteristics and non-traditional digital esthetic values extracted from previous studies. *Source:* The researcher

1. The expressive stage of the shape	11. Liquid crystal case strategy
2. Stage of construction frames	12. Abstraction and simulation of nature
3. Shape closure	13. Flying
4. Type of surfaces dynamic simulation	14. Fragmentation
5. Form interactivity	15. Disassembly
6. Realistic Shape	16. Flow
7. Type of formal transformation	17. Distortion
8. Digital expressive surfaces	18. Dynamic
9. Reactive and formal changes	19. Breaking routine
10. Unexpected hybrid forms by using genetic algorithms	

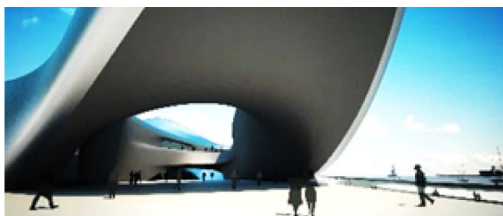


Fig. 6 Project of Regium Waterfront

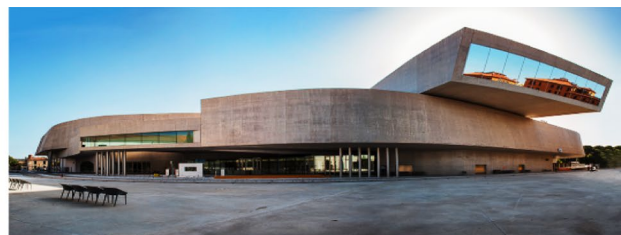
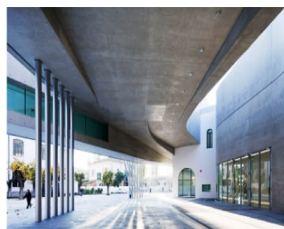
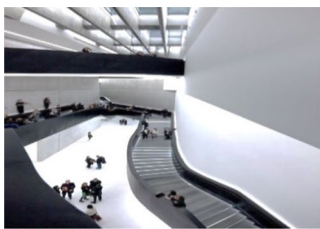


Fig. 7 Project of Maxxi, National Museum

spective points and sidewalk paths follow the shape of the massive to pass beneath the protruding mega blocks. The flowing lines also give a sense of direction Zaha's initial manual drawings represented a streamline of connecting the project with his urban environment, and the use of the computer was limited to fine-tuning the shape. The structural intersections were used to connect the structural structure of the three levels of the building. Cement based on the addition of fine materials was used, in addition to the use of laser technology to ensure accuracy and smoothness in the execution of the molds during casting [24].

3. Collins Park Garage Beach Project in the Coast of Miami 2012 (Fig. 8)

It's a project is a five-storey car park accommodates 460 cars with a pedestrian gathering area, and pedestrian paths connected to the surrounding areas, the formal transformation of the design is shown by manipulating the slopes required for the function of the building as a parking to create varied viewing angles for the beholder, while introducing of the natural daylight, hiding the parked cars, also the design includes liberating the ground floor by making it transparent to emphasize the lightness of the shape,

the building's appearance reflects the connectedness with the surrounding area of the urban spaces to revitalize it, to be a part and gathering center of it. Zaha used the inclined, non-perpendicular columns to support the floors, which give the building a distinctive, gravitational-defiant look that differs from the traditional buildings designated for parking cars, as well the provenance in this project plays an attractive look and welcomed for the visitor by using protruding surfaces and balanced flowing shapes, and here the provenance plays an esthetic role in addition to its original function of attribution [25].

4. An Edifici Campus Form in Barcelona, Spain 2006–2007 (Fig. 9)

It's a university campus, which in Zaha Hadid used the formal transformation of the design by manipulating the floors of different floors using multiple networks. More than one network can be observed that control in the scheme, that design represents the idea of creating a insulating between the exhibition and the university campus and incorporating them into one building, and rehabilitation of the near waterfront to the project in a dynamic style that by using the protruding block ridges to raise the building from the level of the natural ground, which using what can

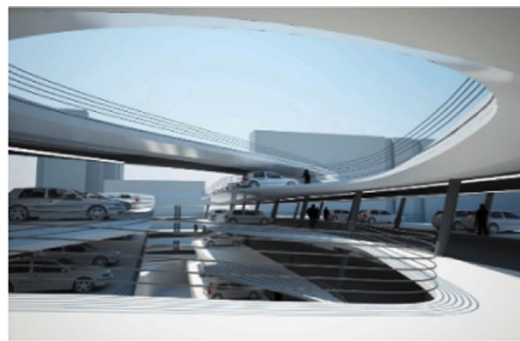


Fig. 8 Project of Collins Park Garage Beach



Fig. 9 Project of Edifici Campus form in Barcelona

be described as a series of spiral waves in the formation and iron was used in the structural structure due to the large area suspended overhangs, in addition to the use of reinforced concrete in the vertical axes of movement and vertical services[26].

5. Phaeno Science Center Wolfsburg Project in Germany 2000–2005 (Fig. 10)

It is an interactive center for science, where Zaha Hadid used the conical shapes to achieve the design's formal transformation by raising the first floor 7 m from the level of the natural ground which used hollow conical blocks, that making it look floating above it, and used one of these cones as an entrance to the project and another as a lectures hall, whereas the rest used as a coalescing exhibitions with the presentation spaces, Where is located on the first floor. It is an interactive center for science, where Zaha Hadid used the conical shapes to achieve the design's formal transformation by raising the first floor 7 m from the level of the natural ground which used hollow conical blocks, that making it look floating above it, and used one of these cones as an entrance to the project and another as a lectures hall, whereas the rest used as a coalescing exhibitions with the presentation spaces, Where is located on the first floor. It is made by adding particulate materials to it that qualify it for use in the implementation of inclining and high walls to overcome the problem of the presence of heavy reinforcement, in order to provide the possibility to implement furrowed corners, fragmented surfaces and bold frames by creating clean surfaces without striations due to the high fluidity of this type of

cement, in addition to its other characteristics such as better strength resistance and ease of pouring [27].

6. The Reinhold Messner Museum project in Italy 2017 (Fig. 11)

The building was constructed entirely of mounded cement to appear as part of the mountain, and the reception hall (underground) with a single entrance leads to the other halls overlooking the valley, and the project is characterized by the ambivalent combination between stability in that it is embedded in ground and covered with grass and between the highlight part that boldly protrudes from the edge of the mountain site, which represented a special design feature in defying the gravity [28].

5 The results

The results of the matrix measuring the extent to which formal characteristics and digital aesthetic values are applied and achieved were formulated in previous study cases in Table 3, where the presence of the parametric formal characteristic was expressed in the study case in a square symbol in red, and in the absence of the parametric formality of the study case, a square symbol was placed in white, and then the percentage of frequency of the parametric formal property was calculated in all study cases by collecting the number of red squares and dividing them into the number of white squares, Then the percentage of the size of each property was calculated relative to the total size of all the formalities and other parametric aesthetic values, as follows in table (3) and The percentage (%) of each element of the formal characteristics and non-traditional aesthetic values in



Fig. 10 Project of Phaeno Science Centre Wolfsburg



Fig. 11 Project of The Reinhold Messner Museum

Table 3 The matrix of formal characteristics and non-traditional digital esthetic values extracted from previous studies and applying to the selected study cases. *Source:* the researcher

Nontraditional formal characteristics and aesthetic values	Cases of applied study						Frequency percentage	Frequency percentage of item size for other items
	(exist) <input checked="" type="checkbox"/> (nonexistent) <input type="checkbox"/>							
	1	2	3	4	5	6	(%)	(%)
1- The expressive stage of the Shape	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	66	6
2- Stage of construction frames	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	83	7
3- Shape closure	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	50	4
4- The type of dynamic surfaces simulation	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	16	1
5- Form interactivity	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	100	8
6- Nonrealistic shape	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	100	8
7- Type of formal transformation	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	66	6
8- Digital expressive surfaces	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	66	6
9- Reactive and formal changes	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	50	4
10- Unexpected hybrid forms by using the genetic algorithms	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	83	7
11- Liquid crystal case strategy	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	83	7
12- Abstraction and simulation of nature	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	33	3
13- Flying	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	83	7
14- Fragmentation	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	33	3
15- Disassembly	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	33	3
16- Flow	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	33	3
17- Distortion	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input type="checkbox"/>	50	4
18- Dynamic	<input checked="" type="checkbox"/>	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	83	7
19- Breaking Routine	<input type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	<input checked="" type="checkbox"/>	83	7

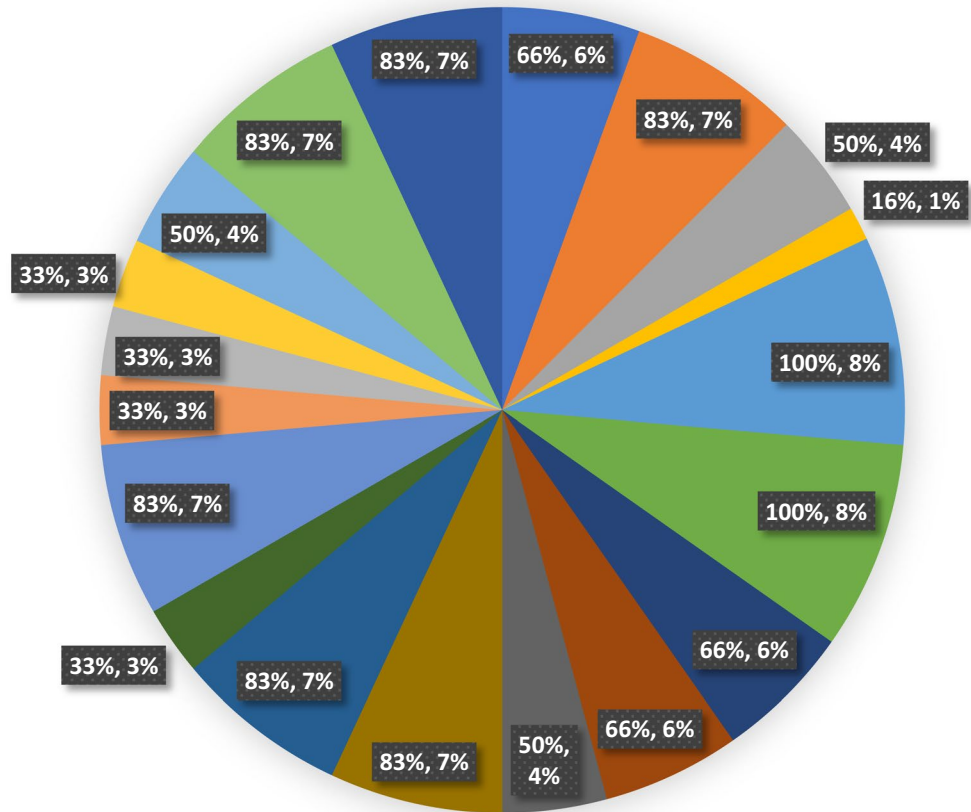
digital architecture based on the results of the applied practical study and their size in relation to the rest of the elements in Fig. 12.

The results of applying formal characteristics and digital esthetic values to study cases are formulated in Table 3.

6 Discussion

The results of the extent to which the elements of the formal characteristics and the non-traditional esthetic values match on the selected study cases were arranged in descending order from largest to smallest in percentage as follows:

1. The first ranking with the highest percentage that reached 100% in all study cases was to the (Nonrealistic shape) and (form reactivity) elements, and the ratio of the size of each of them in relation to the total size of all elements of the formal characteristics and non-traditional esthetic values reached 8%. The second ranking with a percentage of 83% in all study cases was to each of the following elements (breaking routine), (dynamic), (Flying), (liquid crystal case strategy), (Stage of construction frames) and (unexpected hybrid forms by using the genetic algorithms), and the ratio of the size of each of them in relation to the total size of all elements of formal characteristics and non-traditional esthetic values reached 7%. The



- 1- Expressionism stage of the form
- 2- Frameworks established
- 3- closed form
- 4-the type of dynamic surfaces simulation
- 5- Form reactivity
- 6- Non-realistic form
- 7- Type of formal transformation
- 8- Digital expressive surfaces
- 9- Frenetics and formal changes
- 10- Unexpected hybrid forms by using the genetic algorithms
- 11- Liquid crystal case strategy
- 12- Abstraction and simulation of nature
- 13- Cyclisation
- 14- Shivering
- 15- Dismantlement
- 16- Streamline
- 17- Distortion
- 18- Dynamic
- 19- Breaking Routine

Fig. 12 The percentage (%) of each element of the formal characteristics and non-traditional esthetic values in digital architecture based on the results of the applied practical study and their size in relation to the rest of the elements. *Source:* the research

third ranking with a percentage of 66% in all study cases was to each of the following elements (digital expressive surfaces), (type of formal transformation) and (expressive stage of the Shape), and the ratio of the size of each of them in relation to the total size of all the elements of the formal characteristics and non-traditional esthetic values reached 6%. Fourth ranking with a percentage of up to 50% in all study cases was to each of the following elements (distortion), (Shape closure), (frenetic and formal changes) and (abstraction and simulation of nature), and the ratio of the size of each of them in relation to the total size of all elements of the formal characteristics and non-traditional esthetic values reached 4%. Fifth ranking with a percentage of 33% in all study cases was to each of the following elements (Flow), (dismantlement) and (fragmentation), and the ratio of the size of each of them in relation to the total size of all elements of formal characteristics and non-traditional esthetic values reached 3%. Sixth ranking with a percentage that reached 16% in all study cases was to the element (the type of dynamic, surface simulation), and the ratio of the size of this element in relation to the total size of all elements of formal characteristics and non-traditional esthetic values reached 1%.

2. Pursuant to the forgoing, we conclude that the most important characteristic of buildings in parametric digital architecture, in most of them, is the lack of realism to a very significant degree, and we always find a clear increase in the interaction, vitality and dynamism of buildings with the surrounding environment.
3. While we conclude that the least characteristic of the parametric digital buildings is the simulation of nature or the tendency to everything that is traditional, as well it is often inclined to everything strange and unfamiliar.

7 Conclusions

1. The values of stability, solidity, weight and stability are not available because they are directly linked to the traditional form, which is rejected by parametric digital architecture because it is contrary to the creative state of creating something new and unconventional.
2. Reducing the human component in the operational location of projects and replacing it with industrial robots for implementation and construction.

3. Observe the extent of the impact of digital architecture on the architectural formation in a clear and large way.
4. New horizons and different perceptions have been opened for the use of building units and materials in architectural vocabulary, both internal and external.
5. In digital architecture, the importance of standardization and traditional standardization of the shape and sizes of construction units has decreased, so there is a multiplicity of composition, diversity and freedom of ideas infinite.
6. Parametric modeling is mostly based on formation, generation and manufacturing.

8 Recommendations

1. The need to keep up with the architecture of the tremendous digital development in the field of digital architectural design so that the architect is an influential, effective and powerful element in the modern architectural design process and not just to impose solutions on him.
2. The need to work on more academic scientific research in the field of digital architectural design and develop the architecture curriculum in universities to include these topics, and the student has a strong knowledge of them.
3. The importance of limiting and studying the specifications of the creation of the parametric model because it is the backbone and the basis of the parametric design process in digital architecture.

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Authors' contributions

There is only one author who contributed to the whole work. The author read and approved the final manuscript.

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Declarations

Ethics approval and consent to participate

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Consent for publication

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