Coexistence of form and structure in contemporary architecture

Ahmed Hashim Hameed El-Eqapy\textsuperscript{1*}, Marwa Mohamed Kassid AL-Zaidy\textsuperscript{2}
\textsuperscript{1}University of Technology, Architectural Eng. Dept., Baghdad, Iraq.
\textsuperscript{2}Ministry of Electricity, Baghdad, Iraq.
*Email: 90047@uotechnology.edu.iq

Abstract: The reality of contemporary architecture refers that the architectural form may not always reflect the structure of the structure. There are two different models in the relationship between the form and the structure: one contradicts the form with the structure while they work separately, and the other in which the form stems from the structure, overlaps and is compatible with it. Developments in structural engineering have profoundly influenced architecture, where the use of new structural materials and new structural systems to define the formal characteristics of contemporary architecture, the emergence of digital programming and parametric design enabled a return to historical tectonic symbols and self-modulation in the natural structures and materials science and analysis to create a contemporary architectural structures. From here came the desire to explore the nature of this coexistence relationship. The main objective of this study was to clarify the relationship of form with the structure by giving a clear vision about one of the types of form correlation with the structure, which is the relationship of coexistence in which the form stems from the structure that the structure reads the form and be the source of its creation. The problem of research is the lack of clarity of the formal and structural harmonic relationship and the ways for achieving this harmony in contemporary architectural products. The main elements are derived from the concepts related to research and analysis of the set of architectural applications that achieved the case of coexistence and the practical application, and then come up with the results and conclusions that related to the case of formal-structural harmony in contemporary architecture which is achieved through a combination of intellectual, symbolic and material factors with digital techniques.

1. Introduction
The architectural structure and form are two major components in the formation of buildings. The interaction and conflict between these two components and their balanced growth in the process of manufacturing and development of building techniques led to the creation of a new generation of buildings with an advanced technological structure in which the structure is a generator for the form. The shape stems from its structure and the aesthetic expressions (tectonic) are united or may be harmonious (acting as a whole). In other words, the relationship of form and structure is one of harmony. The fact that the state of harmony is characteristic of contemporary architecture as it is a case that achieves the visual balance and coexistent in the relationship of architecture dual (form and structure).

2. Research problem
The uncertainty of the relationship between structural-formal coexistence and the ways for achieving this coexistence in contemporary architectural products.
3. Research objectives
The main objective is to clarify the relationship of the form with the structure by giving a clear vision of one of the types of link of the form with the structure, which is the relationship of coexistence in which the form stemmed from the structure, that is, the structure reads the form and be as its source of creation.

4. Research methodology
- Building a theoretical framework with diverse concepts on the subject.
- Studying and analyzing the selected contemporary applied architectural samples that achieve the state of coexistence between architectural form and structure.
- Conducting the application of the theoretical framework elements of the selected samples.
- Exploring the coexistence relationship between form and structure and the ways needed to achieve that, and then presenting the findings and conclusions.

5. Part 1

5.1 Coexistence concept
Coexistence is given under the term "synthesis" in English, as stated in the Lexicon which means:
1. The composition or combination of parts or elements so as to form a whole.
2. The combination of often diverse conceptions into a coherent whole (combine to form).[1].

5.2 The most important aspects of coexistence (form and structure)
There are many architectural studies that deal with the concept of form and its relationship to the structure, in which the term architectural form is often used to express the external structure of the architecture. Although, these studies have left a limited definition of the architectural form free of structural considerations, in which the architectural form is understood and limited to the form of covering or the external form, excluding consideration of internal structure organization and recognizing the external structure as a three-dimensional structure that may not be fully linked to structural form.[2].

But Ching's definition of architectural form is more comprehensive, describing it as a comprehensive term that refers primarily to the outline or shape of the building, and to a lesser extent to its internal organization and its uniform principles. It is also noted that this form includes various visual and relational characteristics: (size, colour, texture, position, orientation and visual inertia from his point of view), so generally we understand in the first place that the architectural model includes not only the exterior or three-dimensional block, but also includes additional architectural aspects including structure, insofar as they may regulate and standardize architectural design.[3].

Thus, the architectural proposal confirmed that the structure of the constants of the definition of the mass structure of any building and that with the formal design, they may define the external mass of the building and give it the uniqueness and identity of its own, hence the idea of creating coexistence between both form and structure to be stemmed from each other. The Table (1-1) represents a proposal of the thought of architects who used the frame structure as the basis for creating a formal structure of the building:

Table 1. The thought of architects who used the structure as the basis for creating the structure of the building [4].

| Architectural building pictures | Architectural example | The design idea | The Architect |
|---------------------------------|-----------------------|----------------|--------------|
| ![Elko city Hall](image) | Elko city Hall | Inspiration from the human body in the design | Santiago Calatrava |
|                                |                       | Having a structure as a base for the design | |
Using technology as a constant for all parts of the building (decorative or functional)

Shanghai Bank
Norman Foster

Use the interface as the main structure designed for the outer shell

Birds’ nest stadium
Herzog and De Meuron

From what is mentioned in the preceding paragraph about the concept of coexistence, it is found that the aspects of coexistence between form and structure are overlap, harmony and unity. Through Table (1-1) above, it is clear that the formal structural harmony has levels of thought set by the pioneers of architecture that achieve the principle of coexistence. The most important of which: (The relationship of coexistence promoting to human thought, the relationship of coexistence promoting to technical thought, the relationship of coexistence that achieves formal tectonic unity).

5.2.1 The relationship between the form and the structure

The shape or mass of the building, or any external details, dominate visually and calls for exploring the relationships between architectural form and structure, but before considering the diversity of relationships between these forms (which designers can exploit for architectural enrichment and give it multiple meanings), and their structures, there are many things require clarification. Previously, the structure only provided stability to the building, and could not be an establisher of form and architectural space.[5]. But such an approach creates limited thinking and an asymmetry between the shape of architecture and its structural systems, and thus architecture loses its identity and becomes a horizontal and vertical coverage of the structure of the building at that time. Also, this asymmetry between structure and form can rapidly destroy the structure after its implementation and fall due to lack of sufficient strength and stability.[6].

After the Industrial Revolution and the emergence of modern architectural thinking and the subsequent formation of new architectural ideas such as high technology, Deconstructing and folding ...., New horizons have emerged in the area of dealing with the structure. Since the structure has become unstable and can be combined with non-structural parts and sometimes the structure itself could be the building space such as domes, and in other times the structure and space could be as a group of distinctive elements work together, such as tents where the crust is a weaver or leather does not have the strength and stability required to form a space and depends on a frame structure to support it to work together in harmony and integration.[7].

The relationship between form and structure can be expressed through the ways of dealing with the structure in six ways as follows.[4]:

1- Ornamentation of structure: A structure based on creative aesthetic foundations.
2- The structure as ornament: Any element added to a structural form only for decoration or ornament purposes.
3- The structure as architecture: Structural elements are selected and controlled according to visual standards in the first place.
4- The structure as a form generator: Structures as a base generator of form.
5- Accepted structure: Structural requirements may significantly affect the shape of a building even if the structure is not exposed.
6- Structural requirements ignored: The structure is ignored during the design of the building and will not be considered as part of the formal and aesthetic composition.

5.2.2 Coexistence between form and structure historically

The revision of history to track the relationship of the structure to the form and its role in drawing the architectural form and its integration with it is necessary. Many studies have examined the relationship
of the structure with the form, and how they are combined together during the architectural design process, and during different stages of the history of architecture. The most important of which are:

1. Suckle’s study suggests that architects should define the form and internal planning after considering a wide range of factors that may not include structure such as program development or site and budget studies. [8].

2. The architect Arthur Erickson claimed that the structure is the strongest element in the formation of the mass structure and that if not the basic consideration in a long series of decisions that determine the form, it could distort or modify all other determinants of the building. The author believes that it should not determine the form as the columns dictate but the opposite, where the structure follows the form. The Vancouver State Court building (Figure 1) and the Museum of Anthropology (Figure 2) as examples [2].

![Figure 1. Vancouver State Court Building, Canada, by architect Arthur Erickson [2].](image1)

![Figure 2. Museum of Anthropology Arthur Erickson [2].](image2)

3. Viollet-le-Duc expressed the 20th-century rational structural views: "Impose a structural system, and I will naturally find you (the structure) that should result from it." He took the principles of Gothic architecture into account, where the load-bearing walls of the building and the pillars affect the envelope of the building because of its external and internal spatial impact. [6]. However, since the emergence of tensile materials that can withstand forces such as iron and steel, the previously limited structural elements of walls and basements have changed, and new systems such as pillars, bridges and other systems such as prefabricated concrete, lightweight slabs and glazing systems have emerged. The structure has become somewhat separated from the form, that may be unexpected. Violet Le Duc's beliefs in the structure as a "giver of form", a definite determinant of form, were strongly emphasized in the 1950s and are convincing in the context of high-rise buildings, squares, halls and stadiums, but not in the context of all architectural projects. [9]. It is clear from the above that the relationship of the form to the structure has been subjected to more than one viewpoint during the stages of historical architecture, the first is that (the form is the determinant for structure) and the other that (the structure is the giver of the form).

5.2.3 Coexistence between form and structure in contemporary architecture

Architecture must embody an expression of the ways and materials of its era, as engineers provide the tools of their time and technical knowledge, developments in civil and structural engineering have profoundly influenced architecture. The emergence of digital programming and Parametric design has
enabled a return to historical tectonic symbols and analysis to create contemporary architectural structures [10].

In the AA Research Laboratory of the British Centre for Architecture and Design Research, using a set of Para-Metric programming processes, a rigorous interpretation and reassessment of the Gothic tectonic system which was adopted for its excellence in building accuracy, stability and expression, as well as the power transmission and balance system, is interpreted and reassessed. The result of this design research process will be the creation of complex architectural designs and integration at the whole and part level. These elements are created subjectively and harmoniously according to design protocols and typical contemporary software to achieve unity at the level of form, structure and internal structure [11]. By developing sequential thinking: form, structure, materials to materials, structure, form, and inspiration from the processes of self-formation in nature to discover a more appropriate way to organize architecture in the contemporary approach, simulating the natural system and the ability of nature to distribute the properties of materials in terms of density and contrast, and the production of complex structures led to the focus on the structure and not on the ornaments that are placed on it. Both the structure, form and space understood the building as a set of systems that function as a single unit. The group of professionals responsible for these systems is always a multidisciplinary team that studies the relationship between form and structural characteristics of systems, where it is necessary to include structural approaches from the outset.[12]. To help architects find the best structural solution or to determine the options it is necessary to understand the structural capabilities of the structural components (structural behaviour) such as [10]:

- The proportion between distance and length.
- How forces are distributed in a balanced manner on the edges of the structure and supports.
- Ratio and synchronization are necessary to unload weight and other forces.
- The structure form.

The following diagram illustrates the difference between traditional process and formal-structural integration in the contemporary design process, which includes feedback and continuous improvement on structural design even during the construction phase:

![Diagram](image)

**Figure 3.** The difference between traditional and contemporary design process [10].

It turns out that the reality of contemporary architecture indicates that the architectural form may not be expressive of the structure at all times, as there are two different models, one of which the form stems from the structure, overlaps and familiarize with it, and the other contradicts the form with the structure. The contemporary design process includes feedback and continuous improvement on the
structural design even during the construction phase. The form in the contemporary architectural approach is closely linked to the forces influencing the structure and the reactions of the supporting structure towards the forces influencing it. Thus, the process is characterized by the structural integration and formal structural coexistence, as the form comes from the structure.

### 5.3 Specific cases of coexistence between form and structure in architecture:

There are eight architectural cases where the structure is detrimental to the architectural form:

1. **Shell structure**: Achieves the purest structure and coexistence of architectural forms and structure, also known as "structural surfaces", based on three-dimensional curved geometry and correct orientation, analyzing the influencing forces to other forces that are easy to calculate and control within the minimum thickness. Two types of cortical structures are cortical dome and cortical vault.[10]. The basis of the idea of the original cortical structures is to simulate nature such as eggshells, in which the architectural form is compatible with the structure because it originates from its foundations and acts as a single unit that conveys loads from the roof structure to the base.[5]. Contemporary cortical structures adopt digital modeling in which a structural model of free-form units is created using digital tools and software. To choose the structural form by simulating the real model, then the final structure is selected after being tested by a real simulation of the construction process [10].

2. **Textile structures (Architextiles)**: Includes a wide range of projects and ways of thinking in which the Architecture is unified with Textiles to create a more dynamic, flexible and effective and respond to society's changing cultural requirements, where the resulting form is fully aligned with the supporting structure flexibly and streamlined [13].

Textiles + Architecture = Arch textiles

In contemporary architecture, digital technologies in production and manufacturing have enabled the exploration of innovative structures that combine ergonomically designed engineering and complex structures. Using Mathematical software for the Voronoy algorithm that can be divided into two basic types. The first is a model that starts from the specified data and creates complex shapes. The Second is a model that makes the shape segments connected in a way that is consistent with the idea. These designs are based on the principle of structural generation extended in different directions in a way that is free from constraints and expresses the idea in harmony with nature or function. Computational techniques aim to include new structures that follow digital manufacturing in the architectural configuration, including.[13]:

1. Algorithmic Porous Patterns.
2. Topological Urban Fabric.
3. Strands of Intelligent Matter.

3. **Suspended structure (Catenaries)**: A suspended structure is a type of architecture that refers to an arc that follows an inverted curve. Iron cables have been used in the construction of bridges and are then used to cover architectural spaces with long spans.[14]. The simplest example is a cable in the form of a curtain that runs between two high points, relying on its own weight in the resistance of forces and sometimes reinforced concrete as the material of suspended structures has been selected for this reason as it limits the forces of tension and acts as both surfaces and structure.[5]. In contemporary hanging structures, computer and digital modelling are used to choose the best structural form [10].

4. **Ribbed structures**: generate and define architectural form, although their structural nature often requires a separate packaging system.[15]. Ribbed structures are adopted by contemporary architecture as one of the most important structural systems in the form of T-shaped slabs of reinforced concrete ribbed one-way and two-way. The system adopts the principle of repetition of elements horizontally.
and based on columns pillars [16]. With the help of digital engineering modeling tools designing and evaluating for these architectural models can be done at the same time, then the use of digital manufacturing using the Paracloud Modeller which generates the rib (3D configuration) to be ready for the laser machine (implementation stage). The automation written in Paracloud allows to convert any surface to 3D and configure the data to be ready for manufacturing [10].
5- Framed structures (Tectonic Pillars): A network of beams and columns that are connected to form the structural frame of a building. It is possible to make frames in which columns and beams work as a single part and exhibit uniform static behavior. The isolated pillars of the Gothic cathedral were previously taken as essential visual elements in which they embody the unity of structure and form. Frames draw the space and define the architectural form in full, and attached to the covering to complete the structure of the building. Contemporary high-rise buildings are a typical example [17].

6 - Arches system: Arches form a coexistence state between the structure and form where the structure adopts the principle of repetition as the basis for the generation of structure using repetitive arcs, and the various arches span the site irregularly [5]. Newly, innovative contemporary interiors can be created with the idea of generating multi-layered tectonic systems inspired by Gothic tectonic systems and historical precedents (the most efficient in terms of aesthetic richness, qualitative differentiation, gradient relationships and integral part-to-whole relationship) as a starting point. An analysis of curved and ribbed forms is carried out, as well as the variation of thickness and changing depths, and the results of the structural analysis ultimately lead to the creation of a self-contained robotic design system that will generate a variety of adaptive, organized and complex interiors [2].

7- Folded plates (Folding and Double Folding: A folded system in which the structural form consists of the architectural form of the roofs. The potential of the folded plates can be demonstrated simply by taking a piece of elastic paper and folding it, suddenly we find the paper harden and can stretch as a bundle for a distance without deviating, this is the principle of folded ceilings [18]. Double folding is a new structural approach of the implementation of semi-permeable double-curved structures resulting from the intersection of double-folded rhombic elements [19].
8- Tectonic walls: Tectonic walls integrate structural and formal characteristics. The design of the walls not only dominates the facades, but also determines the interior spaces, as tectonic wall acts as a weight-bearing element in addition to surrounding the space, and transfers loads perpendicularly and space surrounded perpendicular horizontally and vertically [20], its internal structure expresses its outside [21]. On the one hand, the technical structural aspect is integrated with the beauty of the architectural form on the other [22]. In contemporary architecture, digital programs and generative algorithms are used to create simple, complex, and expressive structural wall models.

6. Part II: General application framework

6.1 Constructing the theoretical framework

The theoretical framework for research will be formulated here based on the indicators derived from the above proposals within four key elements as in Table (2-1).

| Key Elements | Sub-elements | Possible values | Symbol |
|--------------|--------------|----------------|--------|
| Intellectual aspect | Digital tectonic design | Simulation | Tectonic Gothic models | X.1.1.1 |
| X.1.1 | | | Self-formation in nature | X.1.1.2 |
| | Form Conclusion Approach | | Mathematical calculations | X.1.1.3 |
| General aspects | | | Genetic algorithms | X.1.1.4 |
| X.1.2 | The form follows strengths | | X.1.2.1 |
| | Learning from the evolutionary and | | X.1.2.2 |

Table 2. Elements of the theoretical framework for research
Nonlinear processes of nature, and not imitating it

| Symbolic dimension X.2 | Expressive and aesthetic dimension X.2.1 | The power of architecture in integrating the relationship of the whole and part X.2.1.1 |
|------------------------|------------------------------------------|----------------------------------------------------------------------------------------|
| Moral dimension X.2.2  | Matching what architecture looks like and what it actually is X.2.1.2 |

| Role of the digital techniques X.3 | Digital modelling X.3.1 | The formal generation |
|-----------------------------------|--------------------------|-----------------------|
|                                   |                          | Mathematical program X.3.1.1 |
|                                   |                          | Funoy mathematical algorithm X.3.1.2 |
|                                   |                          | The real simulation for model X.3.1.3 |
|                                   |                          | Structural Behavior Test |
|                                   |                          | Analyzing models of expected forces X.3.1.4 |
|                                   | Real simulation for the construction process X.3.1.5 |
|                                   | Digital manufacturing techniques | |
|                                   | Self-designed robotic system X.3.1.6 |
|                                   | Paracloud Modeller device X.3.1.7 |
| The physical aspect X.4            | Studying the material behavior X.4.1 | Smart materials X.4.1.1 |
|                                   |                                         | Yarns of smart material |
|                                   |                                         | Algorithmic porous patterns X.4.1.2 |
|                                   |                                         | Nano materials X.4.1.3 |
|                                   |                                         | Advanced structural material according to the structural characteristics of the system X.4.1.4 |

### 6.2 Practical application:

**6.2.1 Shell structures: a project of Shigeru Ban Architects, Center Pompidou-Metz, Museum, 2010, Area: 11,330 m²**

The museum is a model on contemporary shell structures, known as Grid Shell adopted digital modeling to create a structural model using digital tools and programs. The so-called approach of finding the form is the choice of structural form through the simulation of the real model after suggesting the multiple structural possibilities that can be exploited, and then choose the final structure after testing through a real simulation of the construction process. The approach to finding the form included the following set of steps:

1. Create multiple possibilities for the model through:
A- Physical simulation of "natural" forms,
B- Virtual simulation of "natural" forms,
C- Virtual improvement of the model.

2. Generating options for covering the building with the crustal structure by simulating the construction process and testing the influencing forces.

3. Selecting the appropriate materials and systems for the proposed building model [23]. The project will be marked with the code A.

Figure 4. The project Shigeru Ban Architects, Centre Pompidou-Metz [24].

6.2.2 Textile Structures: A project of Station Forecourt envelope, EXE team, 2003.
A proposed design for the underground transport exchange area is distributed modally between buses and regulates the flow of pedestrians. The exterior view of the project embodies the structural capillary that is reflected internally in the transport exchange area. The bar structure of the structure consists of strands of intelligent nano material that respond according to the flow changes. The designers used digital technologies in production by adopting the principle of a structural generation with differential scripts for the Voronoi algorithm in a way that is free from constraints and expresses the idea consistent with the function. The manufacturing is by using 3D printing software to combine eloquence of ergonomically designed and complex structure.[13]. The project will be symbolized as B.

Figure 5. Indoor and outdoor view of the underground transport exchange station, designed by EXE team [13].

6.2.3 Cable Structures: the project of Fallacara & Barberio, Rocalia Stone Pavilion, Eurexpo9, France, 2017.
This project is a living space on a total area of 36 square meters and a height of 3.20 meters, reconnects the past with the present by combining traditional sculpture design with contemporary manufacturing processes. The foundation of the structure is a network of dome curves. Digital modeling and computer have been used to select the best structural form That consists of units managed by computer. Several models were analyzed for expected forces, and samples were tested using robotic digital manufacturing techniques. Digital 3D model shows the technical ability of modern CNC machines with traditional building materials such as natural stone.[25]. This project will be symbolized as C.
Figure 6. Suspended cable structure model [24]

6.2.4 Ribbed Structures: Norwegian Library’s Modern Ribbed Design, 2012
The ribs, wrapped in the form of continuous lines (louvres) to form an internal structure and deflect the exterior facade undulating. With the help of digital engineering modeling tools, these architectural models can be designed and evaluated simultaneously, then use the digital manufacturing of the Paracloud Modeller device which generates the rib (3D configuration) to be ready for the laser machine (implementation stage), where the written automation in the device allows to convert any surface into 3D and prepare data to be ready for manufacturing.[10]. This project will be denoted as D.

Figure 7. the project Norwegian Library’s Modern Ribbed Design [26]

6.2.5 Framed Structures: Project, Foster + Partners, New International Airport Mexico City, 2018
The entire station was placed within a continuous light and lightweight network. The insulated pillars of the Gothic cathedral were taken as essential visual elements inspired by the embodiment of the unity of the structure and form of the project to embrace the walls and ceiling in one flowing form, where the frames draw the void and define the architectural form entirely by identifying space and the emergence of the amplified structure, and attached to the covering to complete the building shape and achieve architectural values associated with the strength and control in the architectural configuration [27]. This project will be denoted as E.

Figure 8. New Mexico City Airport Project [28].
6.2.6 Arch System: the project, Parametric Design Studies on Novel Interiorities for Existing Structural Systems, RN8, Evolo, 2011

The design of the project achieved an innovative internal structure with the idea of generating multi-layer tectonic systems, where all the layers were created in a self-operating manner in a process of development and differentiation based on several experiments on the tectonic system to derive the inherent logic of the system. This interior design was chosen from Gothic tectonic systems, historical precedents that are most efficient in terms of aesthetic richness, qualitative differentiation, gradient relationships and the integration of the relationship between the part and the whole. By using the tectonic system of the Gothic vault, as a starting point, an analysis of the curved and ribbed shapes, as well as the variation of the thickness and depths, attempting to give a prominent character to the architecture of the entire structural system. Finally, the results of the structural analysis lead to the creation of a robotic self-design system, which will generate a variety of adaptive, organized and complex interiors [29]. This project will be denoted as F.

Figure 9. Use of Parametric design to create an early interior design from the repeated arcs system / RN8 design [29].

6.2.7 Folded System: Zaha Hadid Project, Riverside Museum, Glasgow UK, 2011.

The folded paintings of the Riverside Museum, Glasgow, draw the structure in the form of expressive sculptural structure. The structure of the building creates an effective form, with a folded shape that takes a concave and convex shape. The geometric shape was divided into a group of steel sections by CNC machines to adopt high-precision laser machines in cutting the panels and the adoption of robots in the organization of the iron structure of the building through the global positioning system GPS.[30]. This project will be denoted as H.

Figure 10. Glasgow UK Museum, Scotland [30].

6.2.8 Tectonic Walls: Sejima & Nishizawa Project, Zollverein School of Management and Design, 2010

Digital programs and generative algorithms were used to create a simple and expressive structural wall model. The tectonic wall of the project integrates structural and formal characteristics, its interior expresses its outside. It contradicts the very smoothly constructed environment. The aim was to
achieve transparency in the concrete structure. Many large openings were made in the facades to create different daylight positions within the building and the position of the windows is determined by the interior programs by changing the height of the ceiling, each floor has a completely different atmosphere.[24]. This project will be denoted as I.

Figure 11. The internal and external structure unity of the Zollverein School project.[24].

6.3 Practical application on the research samples:
Here, the various indicators in the theoretical framework will be applied to the selected samples to obtain the results of their verification, discussion and subsequent analysis as follows:

**Table 3.** Practical application on research samples

| Key elements | Sub-elements | Symbol | A | B | C | D | E | F | H | I | SUM |
|--------------|--------------|--------|---|---|---|---|---|---|---|---|-----|
| X.1 38/64    | X.1.1 18/32  | X.1.1.1| O | O | O | O | O | O |   |   | 5   |
|              |              | X.1.1.2| O | O | O | O | O |   | O |   | 5   |
|              |              | X.1.1.3| O | O | O | O | O | O |   |   | 4   |
|              |              | X.1.1.4| O | O | O |   |   |   |   |   | 4   |
|              | X.1.2 20/32  | X.1.2.1| O | O | O | O | O |   |   |   | 4   |
|              |              | X.1.2.2| O | O | O | O |   | O |   |   | 5   |
|              |              | X.1.2.3| O | O | O | O | O | O |   |   | 6   |
|              |              | X.1.2.4| O | O | O | O | O | O |   |   | 5   |
| X.2 10/16    | X.2.1 5/8    | X.2.1.1| O | O | O | O | O |   |   |   | 5   |
|              |              | 5/8 X.2.2| O | O | O | O | O | O |   |   | 5   |
| X.3 38/56    | X.3.1 38/56  | X.3.1.1| O | O | O | O | O | O |   |   | 6   |
|              |              | X.3.1.2| O | O | O | O | O | O |   |   | 6   |
|              |              | X.3.1.3| O | O | O | O | O |   |   |   | 5   |
|              |              | X.3.1.4| O | O | O | O | O |   |   |   | 5   |
|              |              | X.3.1.5| O | O | O | O | O |   |   |   | 5   |
|              |              | X.3.1.6| O | O | O | O | O | O |   |   | 6   |
|              |              | X.3.1.7| O | O | O | O | O | O |   |   | 5   |
| X.4 20/32    | X.4.1 20/32  | X.4.1.1| O | O | O | O | O | O |   |   | 6   |
|              |              | X.4.1.2| O | O | O | O | O | O |   |   | 5   |
|              |              | X.4.1.3| O | O | O | O |   |   |   |   | 4   |
|              |              | X.4.1.4| O | O | O | O | O | O |   |   | 5   |
| SUM          |              |        | 168| 21| 12| 13| 13| 15| 15| 12| 13| 13| 106 |
6.4 Presentation, analysis and discussion of results:

6.4.1 Detailed analysis

6.4.1.1 The first principal element (Intellectual aspect)

A- The first sub-element (digital tectonic design)
- The results recorded five cases were achieved for each of the possible values (Gothic tectonic models, self-modulation in nature) within the simulation and four cases were achieved for each of the possible values (mathematical calculations, genetic algorithms) within the approach of the conclusion of the form.

B- The second sub-element (general aspects)
- The results recorded five cases were achieved for each of the possible values (learning from the evolutionary and nonlinear processes of nature but imitate it, evolutionary structural improvement) and achieved four cases of the possible value (the form follows the strengths) and achieved six cases of the possible value (proactive structural analysis).

6.4.1.2 The second main element (symbolic dimension)

A- The first sub-element (expressionistic and aesthetic dimension)
- The results recorded achieving five cases for each of the possible values (the strength of architecture by integrating the relationship of the part with the whole).

B- The second sub-element (moral dimension)
- The results recorded achieving five cases for each of the possible values (match what the architecture looks and what it is actually).

6.4.1.3 The third major element (the role of digital technologies)

A- The first sub-element (Digital Modeling)
- The results recorded six cases for each of the possible values (mathematical program, Voronoi mathematical algorithm) within the formal generation and (autonomous robotic design system) within digital manufacturing techniques.
- The results recorded five cases for each of the possible values (structural behaviour test, analysis of models of expected loads) within the real simulation of the model and (real simulation of the construction process, Paracloud Modeler) within the techniques of digital manufacturing.

6.4.1.4 The fourth major element (physical aspect)

A- The first sub-element (studying the behavior of the material)
- The results recorded six cases of the possible value (threads of smart material, porous patterns algorithm) within intelligent materials.
- The results recorded five cases for each of the possible values (porous algorithmic patterns) within intelligent materials and (advanced structural material according to the structural characteristics of the system).
- The results recorded four cases of possible value (nano materials).

6.4.2 Overall Analysis

6.4.2.1 Types of applied projects

- The results recorded 12 cases of the possible values of each (cortical structures, arcs system).
- The results recorded 13 cases of the possible values of each (textile structures, cable structures, folds system, tectonic walls).
- The results recorded 15 cases of possible values for each (ribbed structures, framed structures).
6.4.2.2 The main and sub-elements

- The results recorded (38) cases for the possible values of the first main element (intellectual aspect) out of the total (64) cases, divided into (18) cases for the possible values of the first sub-element (digital tectonic design) out of the total (32) and (20) cases for the possible values of the second sub-element (general aspects) out of (32) cases.

- The results recorded (10) cases for the possible values of the second key element (symbolic dimension) out of the total (16) cases, divided into (5) cases for each of the possible values of the first sub-element (expressive and aesthetic dimension) and the second sub-element (moral dimension) out of total (8) for each one.

- The results recorded (38) cases of the possible values of the third major element (the role of digital techniques) out of the total (56) cases, which is the same as the verification values of the possible values of the first sub-element (digital modeling).

- The results recorded the achievement of (20) cases for the possible values of the third major element (physical aspect) out of the total (32) cases, which is the same as the verification values of the possible values of the first sub-element (the study of the material behavior).

6.4.2.3 All elements in general

- The results achieved (106) cases for the values of the total possible values of all major and sub-elements out of the total (168) cases.

7. Conclusions

1. The coexistence is the consistency and harmony of the two parties so that the nature of the relationship between them is more powerful and overlapping. The structure of the constants of the definition of the mass structure of any building and, with the formal design, define the outer mass of the building and give it the uniqueness and identity of its own, hence the idea of creating the coexistence between both the form and the structure that one of them stems from the other.

2. The methods of dealing with structure in the architecture of different periods ranged from the complete domination of the structure to the complete disregard of the structural requirements in both form and structure of a building, to the state of harmonious harmony between them to include (structure decoration, ornate structure, structure as architectural design, structure as the generator of form, acceptable structural, ignoring structural requirements).

3. The relationship between form and structure has been subjected to more than one point of view during the historical stages of architecture. The first is that (the shape is the determinant for the structure). Previously, structural considerations were not of paramount importance during the initial design stage when determining the architectural form. The other point of view is that (the structure is the giver of the form), and the exterior view of a good building should be nothing but a visual expression of an effective structural reality to give the model (formal structure) the desired result (form) and not the primary basis of the structure.

4. Due to the impact of technological development and the emergence of digital programs and following the Parametric design, the concept of design of the architectural form had changed and the shape has not been designed randomly but follows a set of rules for formal generation. The most important of them is the influential forces, where the concept of form follows the forces has been emerged, expressing the impact of forces through dealing with the structural behavior of building and materials, and thus, the form became subordinate to them.

5. The reality of contemporary architecture indicates that the architectural form may not always reflect the structure as there are two different models, in one of which the form stems from the structure, overlaps and familiarize with it, and in the other, the form contradicts the with the structure.
6. The contemporary design process includes feedback and continuous improvement on the structural design, and the form in which is closely linked to the forces influencing the structure and the reactions of the supporting structure towards it. The selection of materials is according to the characteristics of the chosen structure, as the forces determine the material and the material determines the structure which in turn creates specific architectural form. Therefore, the process is characterized by integration and structural formal coexistent because the form stems from the structure.

7. Structural research and analysis is a proactive and informed process between the idea and its embodiment, where the structure should be the backbone of the architectural idea. The specific cases of coexistence between form and structure in architecture are eight architectural cases in which the structure is determinant to the architectural form and includes (cortical structures, textile structures, cable structures, ribbed structures, framed structures, arch system, folding system and tectonic walls).

8. The superiority of specific element indicators and values illustrates the role of digital techniques through digital modeling, which includes (formal generation, real model simulation and digital manufacturing techniques) in verification followed by the values of the two elements of the symbolic dimension with both sides (expressive and moral) and the physical side through (the study of the behavior of matter and the use of nano materials and smart materials). Finally, the intellectual aspect through the use of digital tectonic design within the patterns that have been applied to them from projects with the superiority of each of the framed and ribbed structures over the rest patterns of the projects that have been applied. In general, all indicators and values of the elements applied patterns exceeded the percentage of half of the achievement.

8. Recommendations

1. The research recommends conducting laboratory architectural researches to study the properties of local materials and force tests, and follow the digital modeling through the principle of structural generation, to reach contemporary structural models in which the form is compatible with the structure.

2. The research recommends the scientific development of the capabilities of local engineers regarding the use of contemporary technological techniques such as digital modeling and digital manufacturing by the relevant institutions in order to promote local architecture through the creation of architectural models different from traditional patterns.

References
[1] https://www.merriam-webster.com/dictionary/dictionary
[2] Charleson A W 2014 Structure As Architecture (London: Chapman and Hall) chapter 6 pp19.
[3] Ching D K 1996 Architecture: Form, Space, and Order Van Nostrand Reinhold, A division of International Thomson Publishing Inc, (USA).
[4] Azizi M and Torabi Z 2015 The Role of Structure in Creating Architectural Space, Department of Architecture (Iraq: April/Islamic Azad University) Vol 10 (Special Issue 1) pp134.
[5] Charleson A W 2016 Structure As Architecture (London: Chapman and Hall) chapter 6 pp19.
[6] Gomez P A 1983 Architecture and the Crisis of Modern Science (Massachusetts MIT) pp36-44.
[7] Williams C J K 2015 Shell structures Computer-Aided Design Vol 61 (UK: University of Bath) PP24-31.
[8] Suckle A 1980 By Their Own Design Whitney Library of Design (New York, N.Y.).
[9] Quoted in Collins 1998 Changing Ideals in Modern Architecture 1750–1950 2nd ed McGill–Queen’s University press (Montreal: Quebec) pp214.
[10] Qingpeng LI 2018 Form Follows Force Dissertation for the purpose of obtaining the degree of doctor (China: Delft University of Technology) pp31.
[11] Trovalusci P and Panei R 2010 Towards an ethic of construction: the structural conception and the influence of mathematical language in architectural design Proc. of the 1st Int. Conf. on Structures & Architecture (Rome: Italy) pp18.
[12] Interactivearchitecture.org 2016 Architectural evolutionary system based on Genetic Algorithms pp6.
[13] Mark G 2016 Arch textiles (RCA/Columbia USA) pp5.
[14] Gail K 2012 The Catenary Art, Architecture, History, and Mathematics (USA: Towson University) pp47.
[15] Thiel-Siling S 1998 Icons of Architecture: the 20th Century ed Prestel (Munich: Germany) pp125.
[16] Mahmudi and Eslami L 2011 Architectural requirements and guidelines for structural Structures and Architecture Conference (Tehran).
[17] Condit C W 1994 The Chicago School of Architecture the University of Chicago Press pp90.
[18] Tao S and Yukari N 2017 An Overview of Folding Techniques in Architecture Design World Journal of Engineering and Technology (Maharashtra: India) pp12.
[19] Philippe B et al. 2014 Advances in Architectural Geometry (London: England) pp233.
[20] Al-Khafaji A M 2015 Tectonic in Architecture Iraqi Journal of Architecture (Iraq: University of Technology) pp12.
[21] Blundell-J P Modern Architecture Through Case-Studies Architectural Press (Sheffield: UK) pp153.
[22] Khaled R 2010 Tectonics in Architecture published articles series Architecture Engineering Forum International Company.
[23] Anthony S 2016 Intro to Grid Shells OAA Conf. (Toronto: May) pp30.
[24] https://www.archdaily.com
[25] Leardi, L 2018 Stone Pavilion Uses Traditional Form and Technology to Connect Past to Present Arch daily magazine pp4
[26] https://mymodernmet.com/helen-hard-vennesla-library-and-cultural-center.
[27] https://www.citylab.com/transportation/2018.
[28] https://archpaper.com/2018/10/foster-partners-mexico-city-airport-scraped-public-referendum/
[29] Evolo 2011 Parametric Design Studies on Novel Interiorities for Existing Structural Systems http://www.interactivearchitecture.org/architectural-evolutionary-system-based-on-genetic-algorithms.html
[30] Frearson A 2011 Riverside Museum by Zaha Hadid Architects Dezeen magazine.