



Mutual Impact Between Building Form and its Structure

Received 25 February 2022; Revised 20 June 2022; Accepted 20 June 2022

Ingy M. Naguib¹
Mohamed M. Elfakharany²

Keywords

Structural forms, Structure as ornaments, architectural forms, Symbolizing structure forms.

Abstract

Many architects pay little attention to the structural issues when determining the form of a building. This paper aims at increasing architects and structural engineers' awareness about the importance of aesthetic value derived from structural systems and elements in the architectural design form. It also focuses on showing professionals how to read the structure of a building architecturally or at least as parts of an architectural composition rather than seeing it only as the building load carrying parts. The research reviews several literatures to introduce the relationship between architect and structural engineer during the design processes. The review also focuses on understanding the relationship between structural and architectural form through illustrating various classifications and definitions. The review moves into an analytical study on different structural types in accordance with architectural form and style across periodical time. An assortment was concluded from the study to identify the degree and type of this relationship in different architectural styles and movements. Finally, the research concludes through the recommendations; the importance of maintaining the existing strong and mutual relationship between the structure and architecture form for a better built environment.

1. Introduction

It was mentioned by Karl Freidrich Schinlek (Prussian architect 1781–1841) that the art of architectural design form and elements detailing should never ignore or hide the impact of the structural type on the building form [13]. Hence, this research explores the building structural form as a part of architectural work to bridge the gap between architectural and structural engineering perception of the building forms. Integrated studies between these two professions can help students to learn from the external aesthetics of architecture and work to apply the unseen structural engineering principles to create distinctive building with each particular structure.

Based on several accepted views, architectural building design usually follows three main aspects which are 'the function, the form and the structure.' The forms of various architectural

¹ Ingy.naguib@pua.edu.eg - Assistant professor, Department. of Architecture Engineering, Pharos University in Alexandria

² M.fakharany@pua.edu.eg Assistant professor, Department. of Architecture Engineering, Pharos University in Alexandria

styles are intimately related to the systems of structure and the used materials. The relationship between architecture and one of its prime constituent elements, structure, was not always as multifarious or diverse as it is today. However, the mutual relationship between structure and architecture form is a historical one which has developed in history through different available materials and existing structure systems which have also developed over time [3]. The research aims at rising the professional awareness about the the relationship between the structural and architectural form and its impact on the aesthetical value of the building.

2. Methods and tools

The research review relevant work and publications of Macdonald A. J., (2001) (2018) and Charleson A.W., 2005 to understand the relationship between structural and architectural form through illustrating various classifications and definitions. An analytical study will be conducted to analysis architectural building form during different period in accordance with the applied structure system and form. This relation is summarized in a table to identify the degree and type of this relationship. Finally, the research recommended an interconnected learning between architectural and structural engineers to acquire same language the incorporation of structural creativity into the architectural design rather than seeing the structure just as a means of load bearing.

3. Classifications of structure and architecture form

The relationship between structure and architecture forms has been subjected to various definitions and classifications. Macdonald A. J., (2001) (2018) has classified the relationship between building form and its structure into six categories, whereas Charleson A.W. (2005) has identified three categories as shown in (Table 1).

Table 1: Different categorization of building and structure form relationships. Source: derived from [2; 3; 15]

Building and structure form relationships	Macdonald A. J., 2001 & 2018	Charleson A.W., 2005
	<ol style="list-style-type: none"> 1. Ornamentation of Structure 2. Structure as Ornament 3. Structure as Architecture 4. Structure as Form Generator 5. Structure Accepted 6. Structure Ignored 	<ol style="list-style-type: none"> 1. Synthesis of Architectural and Structural Form 2. Consonant Forms 3. Contrasting Forms.

Concluding from these classification and others, a deduced classification can be proposed as follow (see figure 1) [2; 3; 15]:

3.1. Structure as ornament

In this kind of relationship, the structural system of a building is visually recognized, that the structure could actually be seen. This relationship was spread in early period before the modern movement when building materials and structure types were limited. Buildings had used the decorated columns of the classical orders as a source of ornamentation in architectural form. The Parthenon in Athens (5th Century BC) represents an early example of this type in which the form was derived from the structural requirements (see figure 2). Structure as ornament using the classical orders can still be seen recently but not vastly [1].

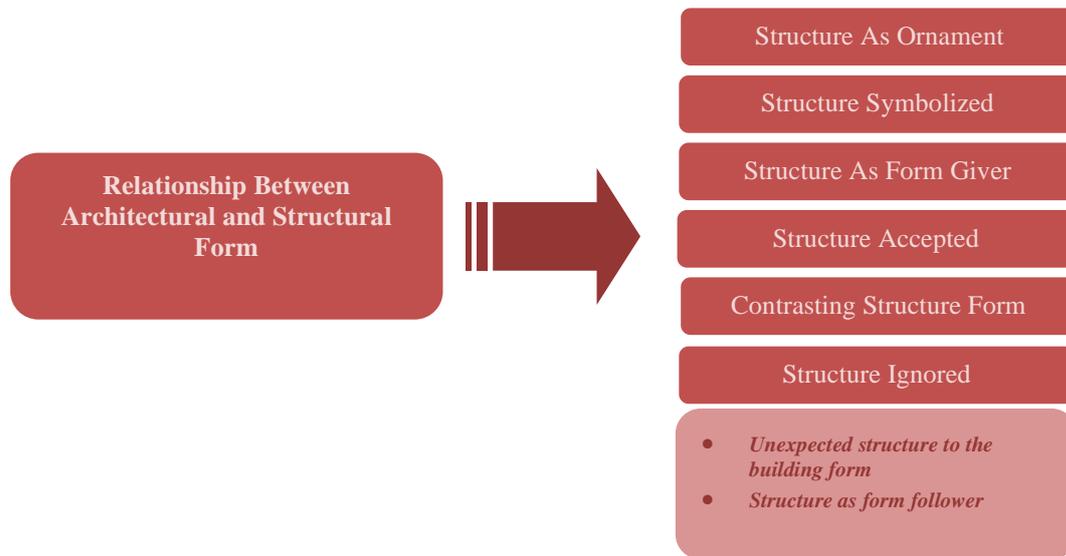


Fig. 1: Shows the concluded Architecture & Structure Form Relationship. Source: adapted by the authors, derived from [2; 3; 15]

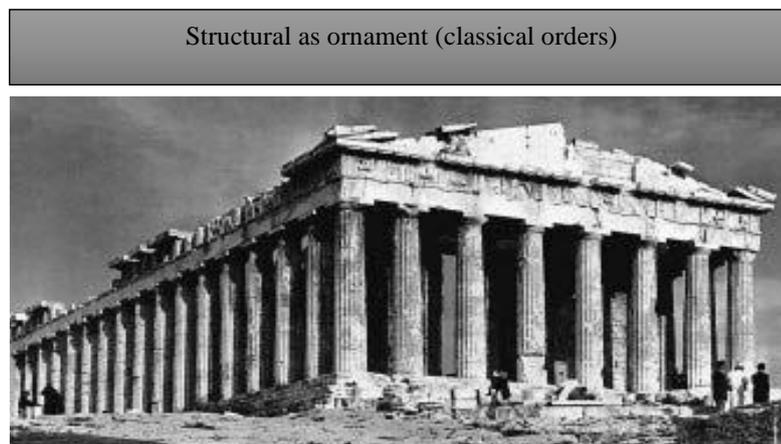


Fig. 2: Parthenon, Athens, 5th century BC. Structure and architecture perfectly united. Source: [1] p.74

Structure as ornament was also obvious in the work of Antoni Gaudi (the Spanish Architect 1852-1926). Gaudi was inspired by the forms found in the natural world and he studied their geometries. Gaudi's ingenious work was known by the advanced study of the structure form and the physical aspects of pressure and gravity. He carefully observed nature and made several experiments to calculate structural loads (using stereotactic model or polifunicular model) to solve many problems that architecture posed. The final unique structural form was used for building external or internal ornamentation. Example for structural ornamentation is found in the Colonia Güell church by Antoni Gaudi (see figure 3) [43].

In the early modern period, many architects such as Mies van der Rohe and Richard Rogers have frequently used the structure of the building as a source of ornamentation. The purpose was to create an architectural style which was celebrating the idea of technical progress and of the condition of modernity. The repetition of the I-section steel beam was used as source of ornamentation in the Crown Hall (see figure 4 (A)). Another example in the modern movement was found in the Palazetto dello Sport. The main structure represented in the inclined exterior struts that resist compression loads from its ribbed-shell roof were exposed around the perimeter of the building to be also used as ornamental features (see figure 4 (B)) [3].

The exposed steel structure of many high-rise buildings, which is used to ensure their stability against lateral loads, can also form a major component of the visual vocabulary that affect the architectural form of a building (see figure 5) [3].

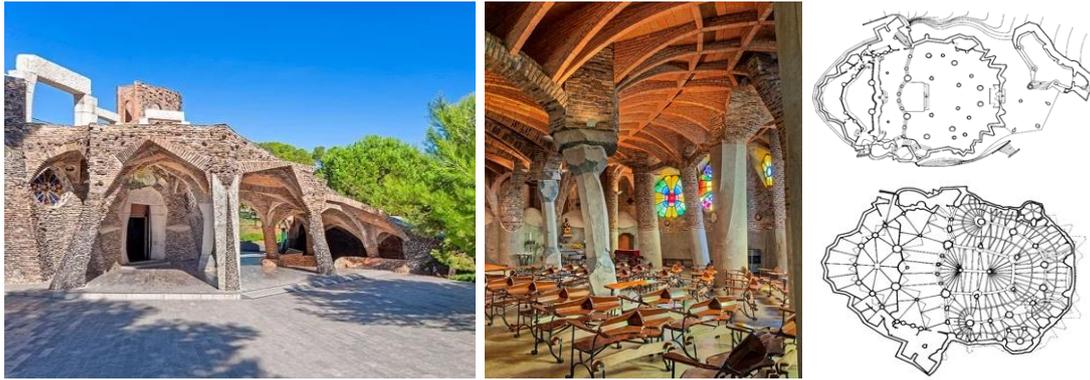


Fig. 3: Colonia Güell (1908-1917) is an example of 19th century innovations by Antoni Gaudí that shows how he used the structure form for the ornamentals of external and internal architecture. Source: [44, 21].



Fig. 4: A) The exposed steel skeleton, including the plate girders that rise above the roof was used as source of ornamentation in the Crown Hall, Chicago, USA, 1952-56, by Mies Van Der Rohe. B) The exposed inclined exterior reinforced concrete struts were used as source of ornamentation in the Palazzetto dello Sport, Rome, 1957, by Annibale Vitellozzi, Source: A: [3]; B: [42] respectively.

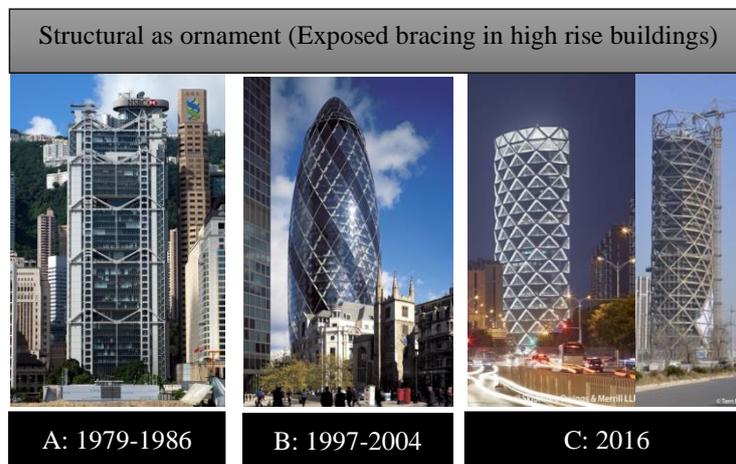


Figure 5: Different forms of the steel bracing in high rise buildings, used as a source of ornamentation. Source: A:[22]; B:[23]; C:[24]

3.2. Structure symbolized

Structure symbolized is a specific type of structure as ornament. In this case ‘structure’ is emphasized visually and forms a major element of the architectural vocabulary. This approach has been employed mainly as a way of expressing the idea of technical progress. However, Angus Macdonald has explained that symbolic intent can also be used for others reasons such as exploring the idea of sustainability. This can be applied by mimicking the structure form of natural organisms as nature always exploits minimum structure and resources for maximum efficiency [3]. In the ‘structure symbolized’ approach, the structure is treated as a set of visual motifs concerning the size, shape and arrangement of the structural elements which are influenced as much by visual as

technical criteria. The technical performance of the structure is secondary to its aesthetic role [1]. Structural representation and symbolic structure are two forms of structure symbolized. The structural representation can be seen as structure mimicking a physical object from the natural world (animals, birds, insects, plants and marine life) or an artifact, like a crane. Whereas, symbolic structure: recalls an idea, a quality or a condition (abstract form). [6]

The education city convention center, Doha, Qatar, (2008-2011) mimics specifically the Sidra tree (Natural world). Traditionally, the Sidra tree was a retreat for poets and scholars, who gathered beneath its branches to discuss and impart knowledge [14]. Thus, the structure represents a cultural symbolic. There are many examples of structural representation originating other than from the natural world. The structural form of Sydney Opera House represents a metaphoric design with reinforced concrete shell roof, symbolizes the sails of a boat (an artifact) blown by wind cruising into the harbor which responds to a maritime theme. Another example is shown in Wohlen High School library roof, Switzerland designed by Santiago Calatrava. The structural form of the roof takes the shape of an open soft-covered book (an artifact) (See Figure 6) [3].

The symbolism inherent in the whole project of the Jewish Museum, Berlin is reinforced by the structural members which play important symbolic roles. The concrete struts-cum are orientated at different angles with varied cross-sectional shapes and dimensions. They pass chaotically across the main stairwell leading to the exhibition galleries. These members symbolize the historical dislocations and horrors experienced by the German Jews. The convincing materiality and scale of the struts suggest structurally important roles, even though their chaotic configuration contradicts such a possibility. Although the struts prop the external wall to some degree, their primary role is symbolic as they enhance the architectural concept (See Figure 6) [3].

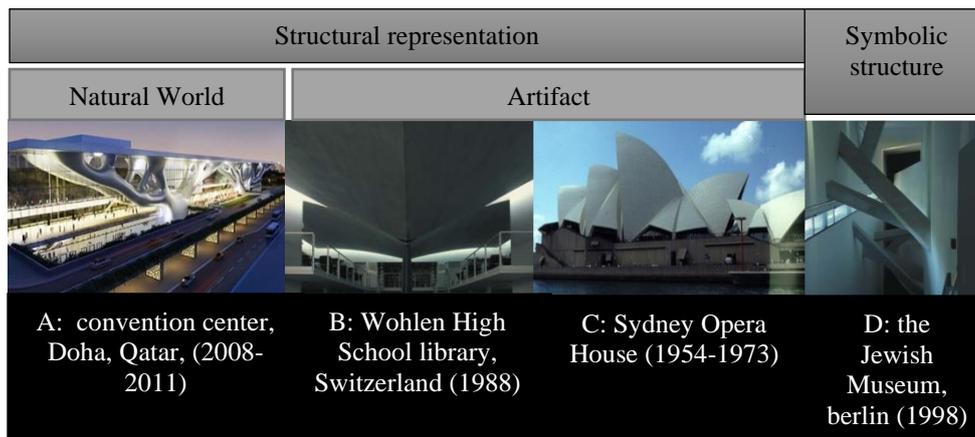


Fig. 6: Shows different examples representing structure Symbolized relationships. Sources: [3]adapted by the authors.

3.3. Structure as form giver

There are two types of the structure as form giver consists of two type which are, form is generated according to structural requirements or as an architectural style. When form is generated according to the structural requirements, the design of the structure influence strongly the forms of buildings where the structure can be exposed or unexposed. In this type, the design of a structural arrangement which is appropriate for the span and load involved simply form the design of a building [2,15]. The masted roof structure integrates with the spiral circulation towers have succeeded in generating the functional requirements of the structural form into a dominant architectural form (see figure 6) [4]. When, the Form is generated from the structure as an architectural style, the overall form of a building may be determined to satisfy structural requirements. The absence of a strong structural material which could withstand tension during the roman and gothic periods has dictated that compressive form-active structures been adopted to achieve the large spans involved. Thus, to create a large interior space of the basilicas and bath houses of Imperial Rome, the large halls were roofed by vaults and domes of masonry or unreinforced concrete The vaulted structures of Imperial Rome are therefore buildings in which

features were necessary for structural reasons were incorporated into the aesthetic programme of the architecture (See figure 7). Many twentieth-century architects attempted to produce a modern architecture in which the same principles were followed. Le Corbusier was one of the most interesting Architects in using the structure as a generator of buildings forms, and the structural technology which he favoured was that of the non-form-active reinforced concrete flat slab, capable of spanning simultaneously in two directions and of cantilevering beyond perimeter columns (See figure 7) [2].

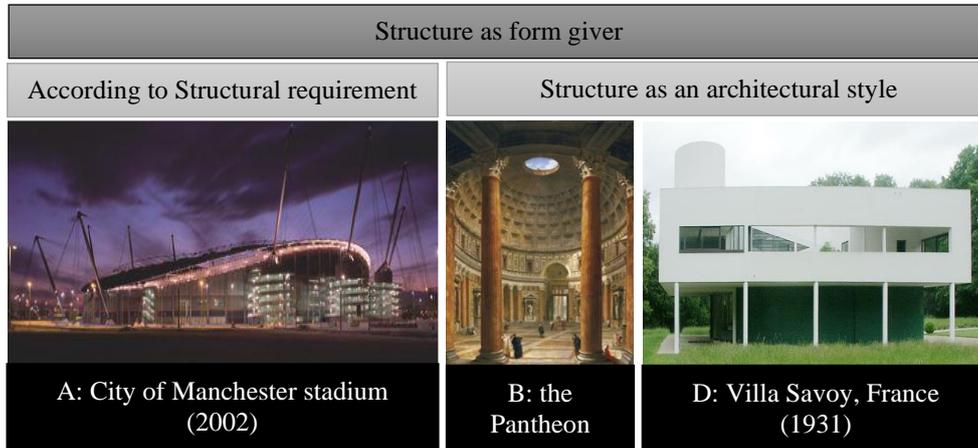


Fig. 7: Shows different examples representing structure as form giver relationships. Sources: [1, 2, 4] respectively, adapted by the authors.

3.4. Structure accepted

In this type of relationship, the structure is not necessarily to be exposed. Whereas the structural and aesthetic programmes are integrated together in harmony. In this case, the architect has the key role in creating the simple architectural form; the structural engineer does not have any influence on determining of the overall architecture form of the building as he just calculate loads to determine the dimension of columns, or the thickness of load-bearing walls already assumed by the architect. However, they should collaborate in certain stage to achieve a highly integrated design. This type appears in buildings that do not have a distinctive form such as any typical modular apartment building (see figure 8) [1].

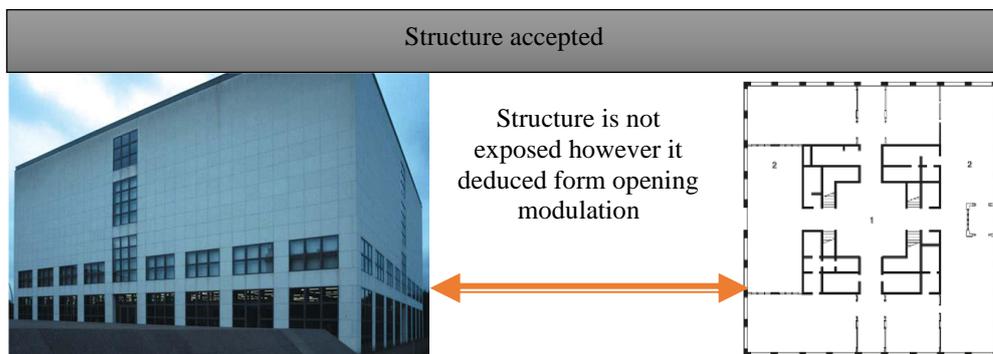


Fig. 8: Shows the modular structure of the Contemporary Art Wing, Hamburg, Germany, 1996 which is accepted to the modular form which forms the outline of the building. Source: [4] p.88

This type of relationship was dominant during the early modern period, where forms of most buildings were relatively straightforward from by using the geometry of the post-and-beam framework. The main reason of using simple forms was that the design and construction of very complex forms was laborious and costly [1]. There were other exceptional examples such as Erich

Mendelsohn's Einstein Tower in Potsdam, and Le Corbusier's chapel at Ronchamp which were successfully realized despite having complex forms unrelated to structural function [2].

3.5. Structure ignored

In this type of relationship, the structure is present to support the building envelope. In this case, the structural engineers function as facilitator, the person who makes the building stand up. The architect who wishes to disregard structural considerations when determining the form of a building must be mindful of consideration of cost and scale. That is because, the buildings forms which have been determined without regard to structural considerations have relatively greater cost to produce than those which have. This type has started, since the development of the structural technologies of steel and reinforced concrete in the late 19th century. At this time, it has been possible to design buildings, at least to a preliminary stage of the process, without considering how they will be supported or constructed. This is possible because the strength properties of steel and reinforced concrete can provide large spans [2]. The final structure form in this case may be present as an unexpected structure to the building form or as a Structure as form follower. In this case of unexpected structure to the building form, the structure does not match with the building form. El Salam theater at el Moaskar el Romani, el Cornish, in Alexandria, Egypt, represents an example of this type of relationship. When looking to the building from outside, the observer may think that the structure is of the shell type. But unexpectedly the interior of the theatre shows that the real structure of the building is of the framed structure type (see figure 9). Structure as form follower were generated during the late 20th century with the introduction of the computer programs which were firstly used as a tool for structural analysis and subsequently as a design aid. This tool has given architects unlimited freedom in the matter of form design as it allowed overly complex forms to be described and helped controlling the fabricating processes. A sculpture form is a specific kind of structure as form follower. The architecture of Frank O. Gehry shows structural form to be extraordinarily subordinate to outward sculpture architectural form [5] [12].



Fig. 9: Different examples representing structure ignored relationships. Sources: A: picture taken by authors; B: [25, 39] adapted by the authors.

3.6. Contrasting structure forms

Architectural and structural forms contrast when a juxtaposition of contrasting architectural qualities such as geometry, materiality, scale and texture are observed. Exchange House, London can represent an example of this type. The contrast between forms in the Exchange house, London arises primarily from the need for the building to bridge underground railway lines, but even the exposed transverse cross-braced bays at each end of the building are unrelated to the architectural form. The parabolic arches support a building rectilinear in plan and elevation was applied to support the needed span while considering the subterranean features (see figure 10) [3].



Fig. 10: Exchange House, London, England, Skidmore, Owings & Merrill, 1993. Showing Arches enable the building to span the site. Source: [3].

The following table will summarize the degree of integration between the structure and architectural form according to the 6 discussed categories. It will also determine the degree of the importance of the architect and the structural engineer role in determining the overall architectural form during the design process (see table 2).

Table 2: Degree of interrelationship between structural and architectural form relationship.

Very strong ● Strong. ◐ Weak ○

Category		Degree of integration between Structure and architecture form	Role of Architect	Role of structural Engineer
1. Structure as Ornament		●	●	●
2. Structure Symbolizes		●	●	●
3. Structure as form giver		●	●	●
4. Structure accepted		○	●	○
5. Contrasting structure form		●	◐	◐
6. Structure Ignored	Structure as form follower	●	●	●
	unexpected structure to building form	○	◐	◐

The previous table shows that there is a mutual relationship between structural and architectural forms with a very strong connection in almost all categories. Only in the type of structure accepted the relation become weak with a priority role of architect as the structural engineer role is only to calculate load imposed on the structure.

4. Relation between architect and structural engineer

Historically, the Architect designer and the structural engineer of a building have been the same person (Master builder) for many years as consequence the interaction was natural, then a gradual move toward a separation between the two professions had taken place so the interaction between these two groups is now seen as a two-way process that's why architectural designs that do not follow conventional forms have often been dubbed Architect's Dream but Engineer's Nightmare. The history of this separation is traced to the middle of the 18th century in the western world; specially to the founding of the Ecole des Punts et Chaussee in Paris 1747 and the School of Military Engineering at Meniere's in 1748. This separation created a big gap between the architect

and the structure engineer, as they become two separate professions and they educate separately without any collaboration which makes them having two different languages [2]. However, in the later 19th century architects began to see the ‘functional’ approach of the engineer as a key element that help them creating free forms. Recently, most buildings, because of the complexity of the project, are often designed by a multi-disciplinary team comprising of architects, structural engineers, landscape architects, planners, environmental scientists, services engineers, and quantity surveyors etc. who work closely together to produce the complete design of a building. Although both architect and structure engineer play a major part in the design process, they are not encouraged to fully understand the work of each other [20]. Thus, Architectural and structural engineering education should overcome this gap, as there is always a relationship between structural form and architectural form of a building even if the degrees of this relation differ from one building to another.

5. Building structure and architectural form across time

This section will illustrate the degree of integration between structural and architectural forms that have created different architectural styles over time. It aims to analysis distinctive architectural buildings in different period to recognize how did the structure affected their physical and aesthetic value.

5.1. Pre-historic period

During the pre-historic period, the structures were built using available materials such as earth and stones. Primitive builders have shaped the architectural structures into geometric forms and mainly they use the circular shape. It is suggested by archaeologists that the circular shape is imitated form the natural forms that they found around such as: the moon and the sun. Structure symbolized or structure as form giver were the two types of structure and form relationship at that time (see Figure 11) [7]



Figure 11: To the left the Stonehenge (the famous megalithic construction used for astronomical usage) ; to the right the pre-historic domestic hut. Source: [27,28]

5.2. West Asiatic Architecture

At this age, religious buildings represent the most significant architecture. They were located on the highest points of the city and also many of them are placed on a raised platform to reflect the prestige of the place. The use of plaster and motifs on sunbaked brick wall distinguishes the facades of this period. Buildings were mostly shaped as U-shape form with the use of limited span materials in roofs like wooden members or reeds, which obligate the small size interiors and the presence of courtyards. Mesopotamian architecture also developed the ziggurat, which represent a massive structure with terraced step pyramid creating receding levels, holding a temple at the summit (see figure12) [7]. Structure symbolized and structure as ornaments were the two types of structure and form relationship at that time.

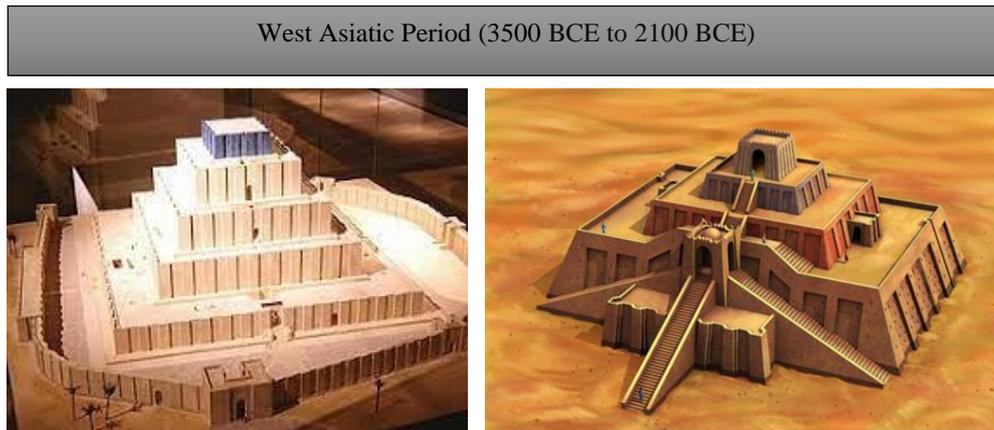


Fig. 12: Examples of Mesopotamian ziggurats. Source: [29]

5.3. Ancient Egyptian Architecture (Pharonic).

Egypt posed a huge deposit of different kind of stone distributed from the lower to the upper Egypt sides. Limestones were found in the lower Egypt, whereas, sandstone and granite were found abundantly in the upper Egypt. At that time, stones as a new emerged technology were used as main building construction material. Stone were the most durable structural material, however, working with stones was very costly and take a lot of time, thus, it was only used for significant building such as religious temples and royal pyramids during the ancient Egyptian period. The pyramid form of the royal pyramids has a philosophical symbol. Thus, the massive pyramid shape of the structure represents a symbolic form for the royal tombs. Whereas, the most common temple forms were rectangular in shape with massive walls made of sandstone. A huge pylon was constructed for the entrance with small openings. This massive wall symbolized the form of most Egyptian temple, it was used to present hieroglyphic writing as kind of ornaments. Huge Egyptian columns were placed close to each other to support the heavy entablature made of stones inside the hypostyle hall and also in the open colonnaded hall. Egyptian columns have different forms, some of them imitate different form of plants such as palms and papyrus plants. While others, can take the form of king status (see figure13) [7]. Thus, structure symbolized and structure as ornaments were the two type of structure and form relationship used for significant buildings during the Ancient Egyptian period



Fig. 13: Egyptian Pylon; B: the Great pyramid of Giza; C: Egyptian Columns at the Temple of Horus in Edfu, Egypt. source: [30,31,32]

5.4. Classical Architecture Period (Ancient Greece and Ancient Roman)

5.4.1. Greek and Hellenistic Architecture

During this period, the stone has limited the construction to the post and beam or lintel forms of significant Greek temples. Greek columns are recognized by their decorative capitals and their elegant proportions. Thus, structure at that time was mainly a generator of the architectural style and form as well as its role as a source of ornamentation. The Parthenon represents an early example of this type in which the form was derived from the structural requirements. Caryatid which is a part that contains six small columns that are sculpted as Greek females supporting an entablature on their heads. In this part the structure is a source of architectural ornamentation for the temple. There were also few buildings that had different form. The Light house of Alexandria (Pharos) built for Ptolemy II in the 3rd century BCE was constructed as a huge stone tower that has a significant different form at this period. Structure symbolized [7]. Three types can categorize this period, structure as ornaments, structure as form giver and Structure symbolized (See figure 14).

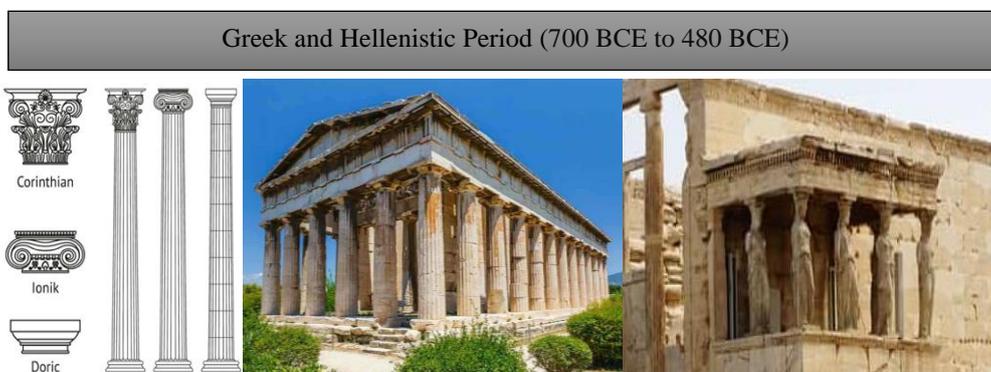


Fig. 14: Examples of ornamental columns used in Greek temples. Source: [33]

5.4.2. Roman Architecture

Ancient Roman was very practical and materialistic. This type of architecture was characterized by the use of vaulted construction for space enclosure, which helped architects to create complex interior spaces without the use of interior supports (see figure 15, B). These included different types of vaults such as; cross vault, barrel vault, dome and semi-dome. At this age the use of concrete wall construction has begun. process masonry-wall construction was the use of “formwork” described by two faces of stone or tiles filling the cavity between them with concrete [7].

There is also the use of classical columns and arches, these act as buttresses in structure or even as decorative elements (see figure 15, A). Those can be found embedded into walls or laid over it. Therefore, structure in this era is characterized as structure as form giver and structure as ornament.

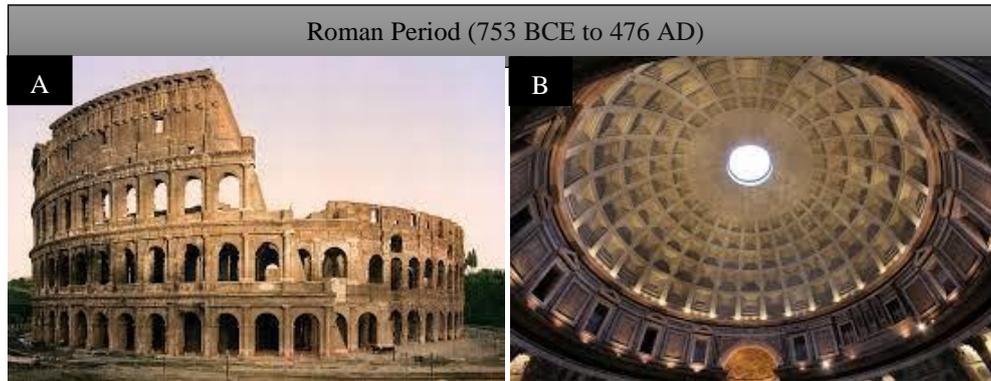


Fig. 15: A: the Colosseum; B: the concrete Dome of the Pantheon. Source: [34,35]

5.5. Gothic architecture

As considered the final phase of medieval architecture, gothic style is characterized by some major structural elements mostly extracted from classical roman architecture which can be defined by abutment, arcade, architrave, barrel vault, corbel, crossing, fan vaulting, etc. Mostly, the existing of vaults and arches are the major elements defining gothic architecture structure [7,8]. Some specific elements original to gothic architecture where flying buttresses, windows with tracery, and piers composed of colonnettes or shafts bundled around a core, which serve as hallmarks of the style. Other decorative element was also used such as fan vault structure which was found in England during the gothic era [9]. Different from roman style this architecture used a skeletal system that transfers load to the ground at discrete points, thereby, expanses of wall to be opened for windows (See figure 16). By studying all these used elements, it can be concluded that structure at this age can be defined as structure as form giver, structure as ornament.

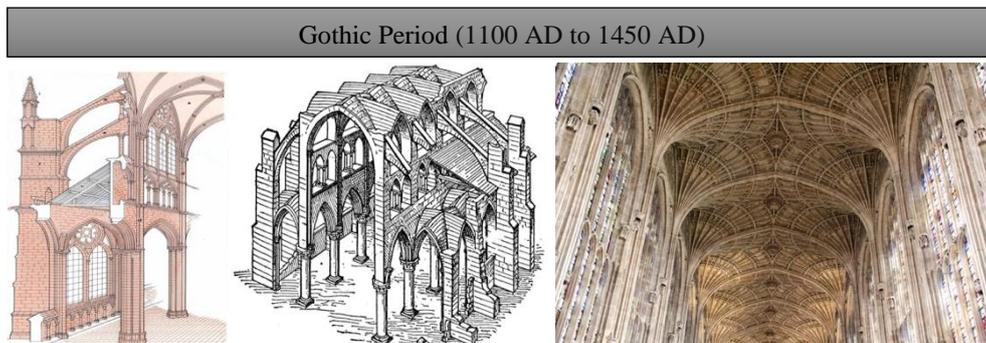


Fig. 16: Using Flying Butters in Gothic Cathedral to create large spans. Source: [36]

5.6. Renaissance

Architects at this period depended on geometry and proportion in design [11]. It adopted renaissance aesthetics features with classical Roman techniques applied in facades, columns and pilasters, arches, vaults, domes, windows, and walls. At this age, more decorative elements are used such as the use of status, ornamental domes, and cupolas (See Figure 17) [7]. This reflects that structure at this age could be categorized structure accepted, structure as ornament.



Fig. 17: Examples of renaissance Cathedral. Source: [37,38]

5.7. Modern movement

Modern style emphasizes function and a streamlined form over ornamentation, it usually involves sharp and clean lines (See figure 16). At this age, significant ideas were born, minimal lines, glass walls, large windows, floorplans [16]. Also, the use of new modern materials including steel, concrete block, iron, and glass. While the use of conventional building materials like wood, brick, and stone is to show natural impacts [7]. This architecture is more open to the natural surrounding environment. In the late modern style, new techniques called “Artificial Intelligence” has reflected the concept of responsive architecture to connect the building with the natural environment [10]. With the development of computer technology and bio-nanomaterial, biomimicry (inspiring from nature) has also been a distinguishable design approach in recent days (see Figure 18). The deconstruction movement led by architects Frank O. Gehry and Zaha Hadid has also created a distinctive and remarkable forms that couldn't been achieved without the good understanding of the structure in relation to building form and benefiting from the revolution in digital technologies, providing new streams of architecture styles demolishing the structural barriers and providing unpredicted building formations resulting from algorithmic design techniques and future innovations in the field of computational design (See Figure 19).

As a result, it can be concluded that structure in modern style is wider in range and could be translated and worked into building with many different impacts according to use, material, or impact, those to be described as structure accepted, structure ignored, structure as form follower, structure symbolized and structure contrasting.

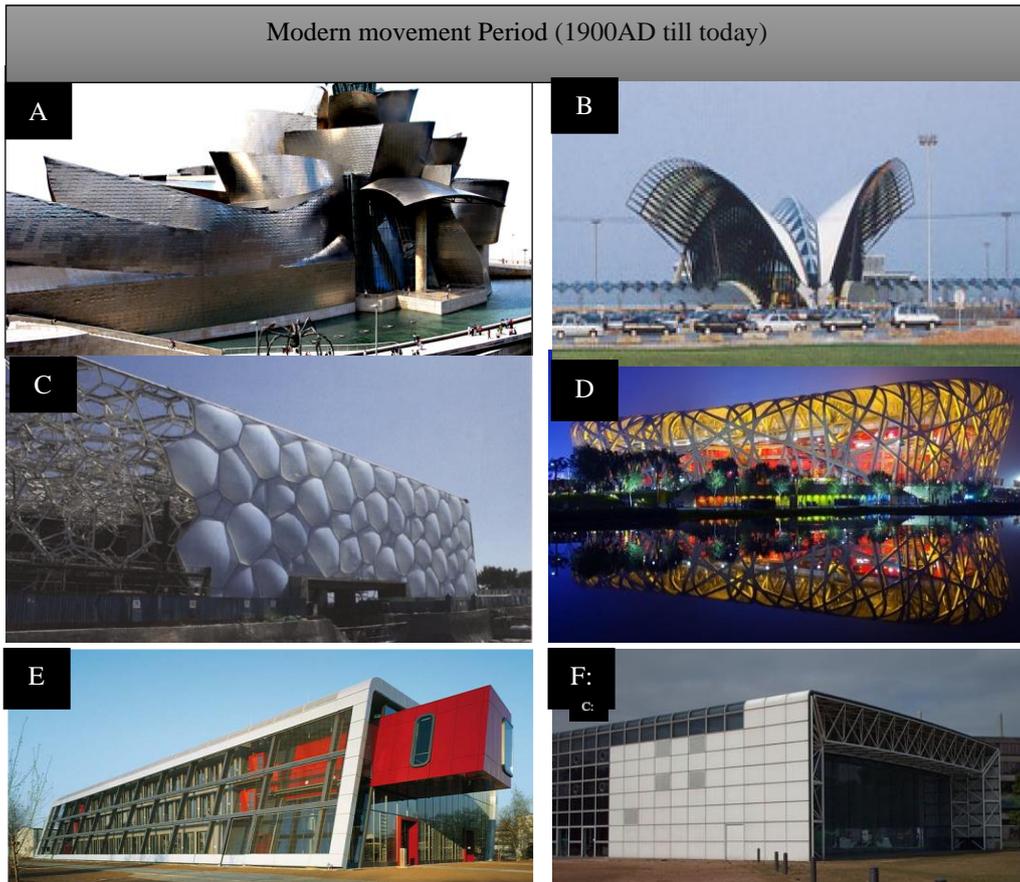


Fig. 18: Different form of modern building style ranging from simple lines to more complicated using computer technologies. Source: A:[25]; B:[18] p.129; C:[17] p.88; D:[40]; E: [19] p. 200; F:[41]

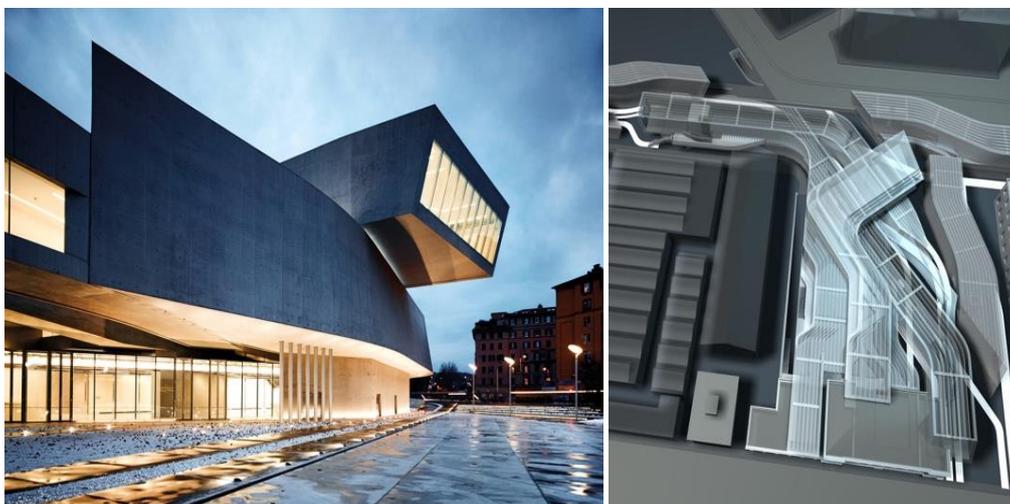


Fig. 19: Deconstruction style of the Maxxi Museum by zaha Hadid, Rome, Italy. Source: [26]

6. Results

From the previous discussed examples which represent each period, the following table has been deduced to identify the types of relationships between the structure and architectural form through the architectural movement and styles (see table 3).

Table3: Architecture styles time line in accordance with structural and architectural form relationship.

Architectural Period	Structural and Architectural form Relationship					
	Ornament	Symbolized	Form giver	Accepted	Ignored	Contrasting
Prehistoric 11,600 BCE to 3,500 BCE		√	√			
West Asiatic 3500 BCE to 2100 BCE	√	√				
Ancient Egypt 3,050 BCE to 900 BCE	√	√				
Classical 850 BCE to 476 BCE	√	√	√			
Gothic 1100 AD to 1450 AD	√		√			
Renaissance 1400 AD to 1600 AD	√			√		
Modern 1900 to Present	√	√		√	√	√

The study showed that starting from the prehistoric age dating back to 11,600 BCE, with extremely limited materials to be used and limited mathematical study to carry loads, structure functioned as form giver and be symbolized to the building function. Afterward, with more education and analytical studies architects got the chance to create more ornamentation and could create bigger spaces with clear structure with accepted loads. By the start of modernism age in around 1900, new way of thinking was created. Building can have completely different structure for the interior and use that can differ from the symbolic outer skin, it also can have a contrasting structure then the interior use design. And this came from the power of material diversity and complicated mathematical analysis and study for different loads. The study also concluded that ornamentation and symbolism are the most common structural design style, both were mostly found starting from west Asiatic era till classical architecture. Then only ornamentation continued till renaissance era, while a big revolution is applied in the modern architecture style. Hence, there is a continues mutual influence that existed between structural and architectural forms and became more connected with the development of modern technologies.

7. Discussion/Conclusion

From this study, it could be concluded that the form of a structural system is inevitably very closely related to that of the building which it supports. The act of designing a building (determining its overall form) is therefore also an act of structural design. As structure can lead to new architectural forms, the architectural forms can lead to new structural types as well. Future technological advances in structural materials and in analysis and design techniques will inevitably continue to increase both the diversity of structural options and their architectural implications. The diversity of structural options leads to a change in the composition and appearance of buildings forms which

cause a change in architectural design and eventually in the attitude of designers and the characteristics of architectural design theories. To achieve and maintain a balanced relationship, the following recommendations are required:

- Architects and Structural engineers should learn together to acquire same language to incorporate structural creativity into their architectural design vision.
- During the design process, they must listen to each other and adjust their approach to achieve a better quality of the built environment.

References

- [1] Macdonald A. J., Structural design for Architecture, Architectural Press, Oxford, UK, 1997.
- [2] Macdonald A. J., Structure and Architecture, second edition, Architectural Press, Oxford, UK, 2001.
- [3] Charleson A.W., Structure as Architecture, a source book for architects and engineers, architectural press, Oxford, UK, 2005
- [4] John G., Sheard R. And Vickery B., Stadia: A Design and Development Guide, Elsevier/Architectural Press, Fourth edition, Oxford, UK, 2007
- [5] Sandaker B. N., On Span and Space, Exploring structures in architecture, Routledge, New York, USA, 2008
- [6] Pearce, P., Structure in Nature is a Strategy for Design, The MIT Press, ch. 2, 1978.
- [7] Fazio M., Moffett M., Wodehouse L., Building across time, McGraw-Hill Education, London, UK, 2018
- [8] Ching F. D. K., Jarzombek M. M., Prakash V., A Global History of Architecture, John Wiley & sons, second edition, New Jersey, 2011
- [9] Mark R., The structural analysis of gothic cathedral, scientific American, 1972. [online]. Available: (<https://static.scientificamerican.com/sciam/assets/File/scientificamerican1172-90.pdf>), Access date: 6/2/2022
- [10] Hussein H. A., Reflection of digital revolution on architecture, International Journal of Engineering Technology, Management and Applied Sciences, volume 3, 2015.
- [11] Moore Ch. H., Character of renaissance architecture, macmilan company, New York, 1905. [online]. Available: https://en.wikisource.org/wiki/Character_of_Renaissance_Architecture. Access date: 6/2/2022
- [12] Trisno, R.; Lianto, F., Relationship Between Function-Form in The Expression of Architectural Creation Advance, 2019. Preprint. <https://doi.org/10.31124/advance.8275322.v1>
- [13] Kathy L., Building to Succeed: Architectural Aesthetics & Structural Engineering, Braunschweig, Black Middle School, Houston teacher institute, 2005. [online]. Available: <https://uh.edu/honors/Programs-Minors/honors-and-the-schools/houston-teachers-institute/curriculum-units/pdfs/2005/structural-engineering/braunschweig-05-bridges.pdf>. Access date: 6/2/2022
- [14] Golasz-Szolomicka H. And Jerzy Szolomicki J. Selected Modern Public Culture and Educational Buildings in Countries of the Persian Gulf. IOP Conf. Ser.: Mater. Sci. Eng. 960 022052, 2020. [online]. Available: <https://iopscience.iop.org/article/10.1088/1757-899X/960/2/022052/pdf>. Access date: 13/2/2022
- [15] Macdonald A. J., Structure and Architecture, Third edition, Architectural Press, Oxford, UK, 2018.
- [16] Thomann L. (February 2022). What is Modern Architecture? Dotdash publishing family, February 2022. [online]. Available: <https://www.TheSpruce.Com/Modern-Architecture-4797910>
- [17] Lecuyer A., Etfé Technology and Design, Birkhauser Verlag AGBasel, Switzerland, 2008
- [18] PETER AND HYATT J., Designing with Glass: Great glass buildings, Images Publishing Group, Australia, 2004
- [19] grömling h. b. d., A Design Manual, Research and Technology Buildings, Birkhäuser Publishers for Architecture, Basel, Switzerland, 2005
- [20] Davison, J B and Popovic, O. A new degree programme in Structural Engineering and Architecture, International Conference on Engineering Education, Rio de Janeiro, Brazil, August 1998
- [21] Casa Batllo. Gaudi Barcelona. Cripta de la Colonia Güell. (April 2022). [online]. Available: <https://www.casabatllo.es/en/antoni-gaudi/guell-crypt/>
- [22] (January, 2022). HSBC Main building. [Online]. Available: http://fr.academic.ru/pictures/frwiki/72/HK_HSBC_Main_Building_2008.jpg

- [23] (December, 2021). 30 St Mary Axe Tower / Foster + Partners. [Online]. Available: <https://www.archdaily.com/928285/30-st-mary-axe-tower-foster-plus-partners>
- [24] (January, 2022). Poly International Plaza. [Online]. Available: <https://www.skyscrapercenter.com/building/poly-international-plaza-dawangjing/16849>
- [25] Zulaika J. Guggenheim Bilbao Museoa: Museums, Architecture and City Renewal. Center for Basque Studies. University of Nevada, Reno. 2002. Retrieved: https://scholarworks.unr.edu/bitstream/handle/11714/4979/Guggenheim_Bilbao_Museoa.pdf?sequence=1&isAllowed=y. accessed date: 26/4/2022
- [26] Zaha H. (December 2010). Zaha Hadid's MAXXI - National Museum of XXI Century Arts. [online]. Available: <http://buildipedia.com/aec-pros/featured-architecture/zaha-hadids-maxxi-national-museum-of-xxi-century-arts?print=1&tmpl=component>
- [27] (January 2022). Why is Stonehenge a remarkable example of prehistoric architecture? [Online]. Available: <https://www.quora.com/Why-is-Stonehenge-a-remarkable-example-of-prehistoric-architecture>
- [28] (December 2021). Prehistory Architecture. [online]. Available: <https://www.english-heritage.org.uk/learn/story-of-england/prehistory/architecture/>
- [29] (December 2021). West Asiatic Architecture buildings. [online]. Available: <https://quizlet.com/527553973/west-asiatic-architecture-buildings-flash-cards/>
- [30] (December 2021). Pylon. <https://www.curriculumvisions.com/search/P/pylon/pylon.html>
- [31] Macdonald J. September 2014. Scientists Have an Answer to How the Egyptian Pyramids Were Built. [online]. Available: <https://daily.jstor.org/scientists-have-an-answer-to-how-the-egyptian-pyramids-were-built>. Access date: December, 2021
- [32] Jackie C. March 2018. About Persian and Egyptian Types of Columns. [online]. Available: <https://www.thoughtco.com/persian-and-egyptian-columns-4092509>
- [33] (December 2020). The Three orders of Greek architecture. [online]. Available: <https://athensandbeyond.com/the-three-orders-of-greek-architecture/>
- [34] (December, 2021). Roman Architecture. . [online]. Available: <https://www.infoplease.com/encyclopedia/arts/visual/architecture/roman-architecture/structural-characteristics>
- [35] (February, 2020). Architecture Timeline - Western Influences on Building Design. The Evolution of Classical Style Architecture. [online]. Available: <https://www.thoughtco.com/architecture-timeline-historic-periods-styles-175996>
- [36] Robert M. (1972). The Structural Analysis of Gothic Cathedrals. [online]. Available: <https://static.scientificamerican.com/sciam/assets/File/scientificamerican1172-90.pdf>
- [37] (December 2021). Architecture of cities. [online]. Available: <https://architectureofcities.com/renaissance-architecture>
- [38] (March, 2013), Response to the Architecture of Early Renaissance. [online]. Available: <https://naponechin.wordpress.com/2013/03/24/response-to-the-architecture-of-early-renaissance/>
- [39] Veltkamp M. Free form structural design. Published by IOS press. Amsterdam. The Netherlands. 2007.
- [40] Bonomo L. (April 2022). Beijing National Stadium. [online]. Available: <https://www.nationalgeographic.org/photo/tdigh-04-06-olympics/>.
- [41] (January 2021). Essential architecture. [Online]. Available: <http://www.essential-architecture.com/ARCHITECT/ARCH-Foster.htm>.
- [42] Rome Municipality. (April, 2022). Rome to renovate a sports arena made of prefabricated concrete. 2021. [Online]. available: <https://www.themayor.eu/en/a/view/rome-to-renovate-a-sports-arena-made-of-prefabricated-concrete-8251>.
- [43] Kliczkowski H. Antoni Gaudí. Loft publication. Barcelona. Spain. 2003
- [44] Nonell J. B., Gabarró G. G. La catedral de Antoni Gaudí: estudio analítico de su obra. Los autores. Edicions UPC. 1998

الأثر المتبادل بين النظم الانشائية والكتلة المعمارية

بالرغم من التأثير المتبادل بين النظم الانشائية والكتلة المعمارية الا ان الكثير من الممارين لا يولون الاهتمام الكافي بالنظام الإنشائي خلال عملية التصميم. يهدف هذا البحث الي نشر الوعي بين المهندسين المعماريين والإنشائيين والتركيز على أهمية القيمة الجمالية المستمدة من النظم الانشائية وعناصر التشكيل المعماري. كما يهدف الي توجيه المهندسين الي قراءة العناصر بصورة معمارية لما لها من دور في التشكيل المعماري وعدم حصر دورها في عملية توزيع الاحمال فقط

يقوم البحث باستعراض مجموعة من الأمثلة التي تلقي الضوء على العلاقة بين دور المعماري والإنشائي اثناء عملية التصميم واستنباط عدة تصنيفات تندرج تحتها هذه الأمثلة. كما يقوم الباحثون بعمل تحليل لسمات النظم الانشائية المختلفة وعلاقتها بالكتل المعمارية ودراسة تأثير الطرز المعمارية على مر العصور. من خلال هذه التصنيفات، تم قياس درجة التأثير بين النظم الانشائية والكتل المعمارية بناء على الطرز المعمارية. ينتهي البحث الي مجموعة من التوصيات بأهمية الربط بين النظم الانشائية والتصميم المعمارية وتعزيز العلاقة بينهم لما له من تأثير علي جودة المنتج المعماري.