Tectonics and Sustainable Architecture: The Notion of Classical and Digital Sustainable Tectonics in Architecture

Yusur Basim Mahmood & Hoda A. S. Al-Alwan
Architecture Department, College of Engineering, University of Baghdad, Iraq
y.mahmood1304@coeng.uobaghdad.edu.iq
hoda-alwan@coeng.uobaghdad.edu.iq

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Abstract

Tectonics–the art of construction- is an essential topic in architectural theory that deals with the potentials of structure, techniques and materials to create poetic architecture. On the other hand, sustainable architecture is a multidisciplinary field concerned with buildings designed for wellbeing, as well as to provide healthy environments while sustaining architectural qualities. The new approaches in architectural research have given way to a distinct collaboration between the two domains (tectonics and sustainability) –in both their classical and digital facets—to constitute what is known as "sustainable tectonics", as a way to generate remarkable and empathic architectural forms.

The article aims to shed light on the practices that adopt implicit thought of tectonics, and its relation to sustainability. The pursuit of sustainability is thus explored through two categories: classical sustainable tectonics and digital sustainable tectonics, to finally extract the mechanism of the tectonic theory and its application in sustainable architecture.

The findings offer a clear mechanism in achieving distinguished architecture, through the integration of classical tectonic factors in passive sustainable practices, and digital tectonics in active sustainable design.

Keywords: Tectonics, Sustainable tectonics, Sustainable architecture, Classical tectonics, Digital tectonics, Passive design.

Introduction

In the late 1980s, architecture witnessed a new design revolution. The ascent of the new paradigm in architecture, namely "sustainability", had led to raise the level of complexity in design, construction, operation, and maintenance of buildings to control the environmental pollution created by human activities; that accounted for an estimated 39 percent of all worldwide greenhouse gases' emissions (Weihong,2011). Consequently, innovative building methods became more significant than ever, and architects strived to implement sustainable solutions in their projects as an integral part of buildings.

In order to cope with this high level of complexity in the building practices, new tools and ways of thinking had to be adopted. In addition, the traditional approaches that hold the value of the building methods had to be re-considered and reviewed to be able to deal with this level of complexity. One of these approaches is the tectonic theory (Al-Alwan and Mahmood, 2020).

The tectonic theory in architecture (denoting the art of construction in general) holds the potential to equip us—during the design process—with a deep structural understanding and detailed spatial perspectives, as a main step towards achieving tectonic architecture (Frampton, 1990). The importance of traditional building crafts that stem from the affluence of local cultures, and the appropriate applications of techniques in construction have led to a high level of meaningful classical tectonic architecture. On the other hand, computer techniques and digital tools have become an integral part of the design process, giving way to a new "digital tectonics" that can contribute—to a large extent—in the generation of new expressive architectural forms (Al-Alwan and Mahmood, 2020).

Many modern practices in architecture that address the real-world problems—especially those related to climate change and global warming—have lost their expressive and cultural design content and have resulted in the lack of articulation in construction (Weihong,2011). Tectonics, as a poetic application of construction, involves a consciousness of meaning within the applied expressive construction techniques that would work within a specific culture and context, towards achieving remarkable and sustainable architecture.

It may be difficult to realize the correlation between tectonic theory and sustainable architecture, but—intellectually—they are linked. The research aims to attach the two concepts and explore the notion of sustainability through tectonics, as well as the effect of new digital tools on the poetic of construction.

2. Theoretical Ideas

2.1. The Notion of Classical Tectonics

Tectonics (as a term derived from the Greek word Tekton which means carpenter or builder) is a central concept that relates generally to the art of building or construction (Frampton, 1990). The first mention of the term was in 19th century by Karl Botticher (1806-1889) who stated that tectonic resembles the amount of internal cohesion between Ontology (functional, structural and cultural purposes) and Representation (aesthetical and expressional purposes of the substance) (Schwarzer,1993). Gottfried Semper (1803-1879) found the essence of tectonics as to grasp the use of different materials and handicrafts to create a cultural expression (Semper, 1989). Eduard Sekler (1920-2017) denotes that building's form evokes emotional responses 'empathy' through tectonic articulation (Sekler, 1965). Kenneth Frampton (b1930), in his book "Studies in Tectonic Culture" in 1995, submits seven factors that describe the essential tectonic elements in architecture. He concluded a comprehensive analytical framework for tectonic theory to become an essential part of the architectural practices. These factors are: (Frampton, 1990).

- Object: represents the architectural parts such as the column, wall, slab etc.
- Details: small units of significance in moral production of meanings.
- Joint: interconnection of the construction and the construing in architectural form.
- Material: the cultural expression of the used material.
- Construction: the physical manifestation of structure.
- Structure: fundamental principle of construction.
- Interaction: the correspondence between site, people and architecture. Fig. 1(a).

Tectonics tends to utilize the handicrafts, details and joints as vital aspects of architectural practices and of significant means of presenting cultural expression, as well as the use of the simplest materials and tools. Therefore, tectonics is a core concept of architecture that deals with the visual aspects of structure, construction, and materials.

Tectonics constructs a virtual communication between Man and his environment, by depending on his ability to recognize the inspirational connection of construction and structure, and creating a interaction between architecture and people in a harmonious manner that evokes emotional responses referred to as empathy (Sekler, 1965).

Accordingly, tectonics is a theory deeply related to application; it is concerned with the method of applying materials to give an expressive form, as well as the way of creating details and joints to be part of the building culture. It also emphasizes the complementarity of the

structural system with the architectural system in an inseparable way. As a result, 'material' 'technique' and 'culture' represent the 'classical tectonic triad'(Al-Alwan and Mahmood, 2020). Fig. 1(b)

2.2. The Notion of Digital Tectonics

With the advent of digital tools into the design process, it becomes hard to interpret the dynamic state of digital production by classical tectonic theory. The term 'digital tectonics' emerged to best clarify the new processes of creation evolved by the digital architectural production. Thereby, digital tectonics is a new version of tectonics that is appropriate with the development of architecture, connecting the classical theoretical concept with the new technologies to reach an effective integration between them (Gao,2004).

Architects and theorists had different perspectives and stances towards 'digital tectonics. Zaha Hadid exploited the merits of tectonic theory as an intricate technique of architectural design considering it as a main method to represent the dynamic ideas of fluid architecture by computer programming, and to grasp the inspirational relationship between force and form, as well as the emotional connection between aesthetics and structural elements (Hadid, 2010). Neil Leach in his study "Digital Tectonics", defines the term 'digital' as an immaterial world of computer algorithms, whereas the term 'tectonics' relates conclusively to the material world of construction. He visualizes the potential of 'tectonics' by the power of computation. With the computer as a promising tool; Leach asserts the ascending need to nurture tectonics sensitivity by the digital media, in a way that allows a continuous dialogue between the ontological and representational layers of architecture (Leach, et. al. 2004). Patrick Schumacher stresses on the adaptation of 'tectonic articulation' as a rational and strategic 'expression' of architecture to achieve social requirements. He emphasized the importance of the development of intricate computer design tools in architecture and other engineering disciplines to give way to more elaborate 'tectonic articulation' and more expressive architecture (Schumacher, 2012). Philip Beesley and Thomas Seebohm, linked the term 'digital tectonics' to both ontological and representational aspects of architecture. They defined it as "a systematic use of geometric and spatial ordinances, used in combination with details and components directly related to contemporary construction", stressing on the way of 'assemblies' of the construction objects (Beesley and Seebohm, 2000). Accordingly, 'tools', 'articulation' and 'assemblies' constitute the 'digital tectonic triad' (Al-Alwan and Mahmood, 2020) as shown in Fig. 2 (a).

Digital tectonics is an evolving version of classical tectonics, it does not refute classical tectonic factors altogether, but the new variable (computer programs) made the architectural production difficult to suffice with classical factors when being analyzed (Al-Alwan and Mahmood, 2020). Architects stressed the importance of using software algorithms to produce complex, controlled, and structurally solved architecture. To enhance the quality of the building is a goal deeply attached with the enhancement of the built environment, by supporting the building's needs immediately (promoting the performance of the building) and optimizing the impact of the building on its environment (Agha,2015). Digital tools have the ability to mimic the real environment. Application of these tools in the design process will have the potential to gain a better understanding of how the building will interact with its environment, to avoid errors before implementation. (Alqalami, et.al., 2020).

The potentials offered by the multiple algorithms start with four main steps: generating alternatives in form-finding process level, optimizing the structure while maintaining the aesthetic aspects, fabricating every small and complex detail, and simulating living organisms to search for optimal solutions. These potentials that computer programs carry out in the design process focus on the idea of creativity in design, and emphasize the importance of existence of all classic tectonic factors. Subsequently, the potentials of digital design programs can be considered as digital tectonic strategies. Four strategies can successfully fulfill digital tectonics represented by: 'generation', 'optimization', 'fabrication', and 'simulation' (Al-Alwan and Mahmood, 2020) as shown in Fig. 2(b).

2.2.1. Generation

Form generation strategy represents the use of computer programs at form finding process level. It takes place at the beginning of the design process, and is composed of symbols and algorithm forms that affiliate the designer needs. Levels of form-generation include generation of details, building elements and structural forms (Kolarevic, 2003).

2.2.2. Optimization

Form optimization strategy ranges between improving shape to improving space. Methods of optimizing form can be: analyzing form, giving alternatives and making an evaluation (Grobman, et.al.,2008).

2.2.3. Fabrication

Form fabrication strategy deals with the production and assemblage of the durable structure of free-form architecture. Presently, designers have a wide range of design possibilities that have been extensively explored in various fields of industrial design, and later exploited in the field of architecture as auxiliary tools to "search" or "invent" these forms. CNC (Computer Numerical Control) and 3D scanners are utilized to explore a new method of assemblage. It includes the processes of production, fabrication, testing and the assembly of the design components (Weihong,2011).

2.2.4. Simulation

Form simulation strategy is an inspiration from Nature and the transformation of living systems into real architectural experiences. Although the structures are complex, they revolve on the basis of realistic concepts that do not give new forms but rather vivid and animated building. The result is 'Nature surrounded by Nature' (Grobman, et.al.,2008).

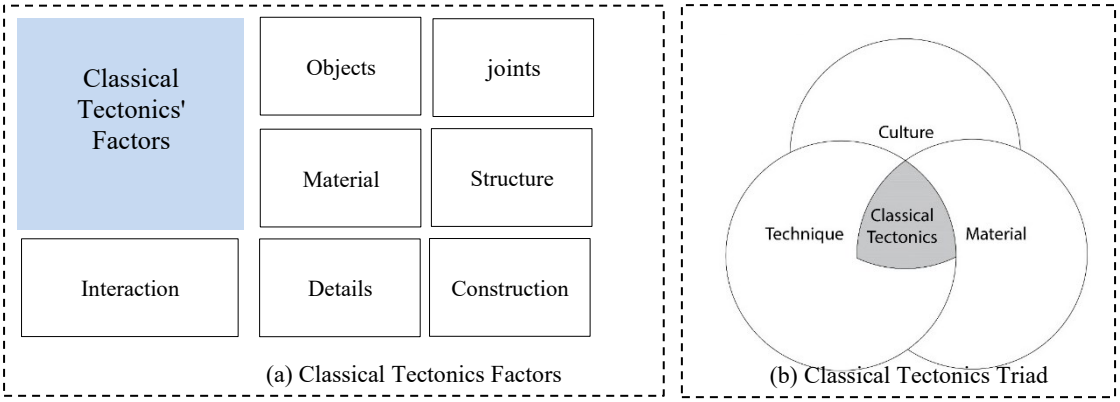


Fig. 1: Classical Tectonics
Source: Author

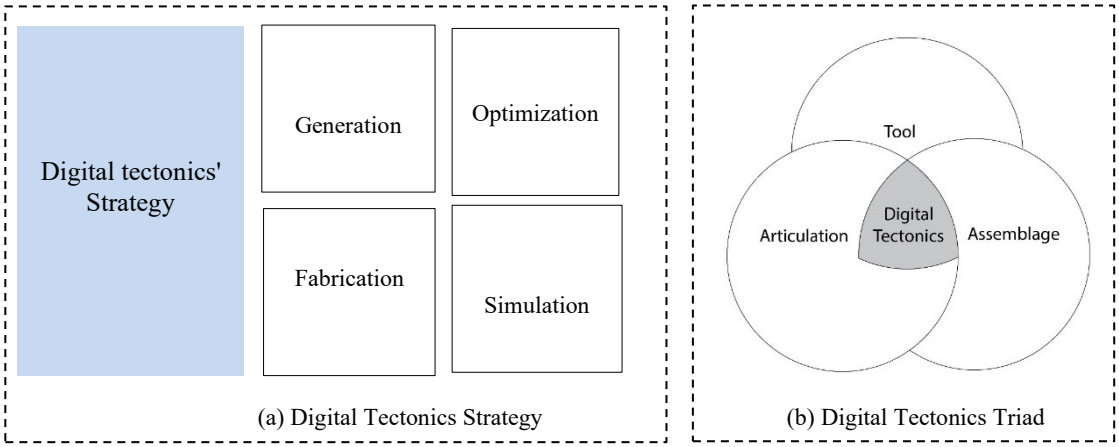


Fig. 2: Digital Tectonics
Source: Author

3. Theoretical Framework

Sustainability; as a field that will continue to evolve in the coming years needs a deep conceptual thinking about its aspiration to go forward. The emphasis on the three pillars of sustainable development (environmental, social, and economic), and discarding the constructional, cultural and arts aspects will not achieve perfect sustainable architecture.
The tectonic theory reconsiders sustainable practices and presents itself as an important tool within the initial stages of the design process, calling for attention to the expressive and cultural aspect of the building, as well as attention to the correct technical application of materials, investment of local resources, potentials of the craft, and finally attempting to interact environmentally (Weihong,2011).

"Sustainable tectonics" is a new dialectic argument in sustainable design process that concentrates on the generative power of structural architecture. This argument focuses on the integration between art and technology, and attempts to find a formal framework of sustainable design by:

- Enabling classical factors of tectonics (object, details, joint, material, structure, construction, and interaction) to find the interrelationships between tectonic theory and sustainable practices.
- Enabling digital tectonics strategies (generation, optimization, fabrication, and simulation) as procedures that can be the initial manipulation of the design process to achieve sustainable buildings.

The concept of 'sustainable tectonics' in this research refers to consider sustainability as the goal and tectonics as a mean to achieve empathic and dialectic sustainable architecture . Sustainable tectonics, as a critical approach is classified into two main categories: classical tectonics and digital tectonics as shown in Fig. 3.

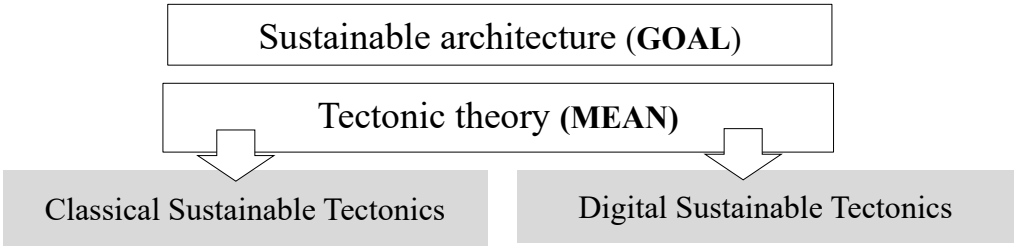


Fig. 3: Sustainable Tectonics Approaches
Source: Author

3.1. Classical Sustainable Tectonics

'Classical sustainable tectonics' is a term proposed by the current paper to describe a tendency to turn back to the local environmental practices; materials and components, and revive the eco-friendly passive systems that are usually low in cost due to their reliance on local resources. The term incorporates the manifestation of the classical tectonics' factors emphasizing the poetic of construction with the cultural expression to make the building contributed significantly in the formation of the city's identity. The full practical application of this approach is vivid in various examples of vernacular architecture, traditional architecture, and diverse practices of modern architecture, where the principles of classical sustainable tectonic design are applied.

Vernacular architecture represents the buildings that are not designed or planned by architects and engineers, but by the builders and craftsmen in response to the localized needs. It exists everywhere around us, but regrettably almost disregarded (Clive,2019). Vernacular architecture inspired architects who developed it into a style of construction and expression, to form what is known as "Traditional Architecture", which expresses a way of building that makes significant and meaningful use of the familiar symbolic forms of a particular culture, of a particular people, in a particular place.

Although the architecture of modernity carried concepts that conflict with the tectonic theory in terms of forms, composition, relation with context, materials and technologies, etc.,

yet many styles emerged from this trend consistent with traditional tectonic principles and sustainability. An example is the organic philosophy of architecture—which is a redefinition of nature's principles as they had been filtered through the creative mind—proposed by the most famous architect of the twentieth century Frank Lloyd Wright, and his teacher Louis Sullivan (en.wikipedia.org). Another example is the Postmodernism –which emerged as a reaction against the shortcomings of modernism- representing an amalgamation of architectural motifs and elements elected from the 'Arts and Crafts' movement and many architectural styles such as: classicism, neoclassicism, rococo, renaissance, etc. Brutalism as an included philosophy in postmodernism had a high level of tectonic expressionism in spite of its effect on the urban decay in its time. (www.architecture.org)

Thus, meeting the environmental and identity requirements, investing the native wealth and exploiting local skills are what the vernacular and traditional architecture achieved. Subsequently, classical sustainable tectonics is based on these four notions: environment, identity, local resources and technology as shown in Fig. 4.

3.1.1. The notion of environment: classical sustainable architecture provided vital connection between man and the environment. Buildings are not always designed by professionals but by builders who learned by trial and error over generations the response to the localized needs, until the buildings became a heritage that formed the culture of the city. The notion of environment includes the following indicators:

- Protection: providing protection from harsh conditions.
- Insulation: providing insulation from noise, pollution, radiation.
- Ventilation: allowing air currents.
- Daylight: allowing accurate amount of sunlight.
- Interaction: achieving interaction between building and environment.

3.1.2. The notion of identity: the core concept of identity in tectonics is simply the distinct character of a place or region reflected by its culture. It includes the following indicators:

- Culture: achieving cultural expression.
- Belonging: giving the sense of belonging.
- Scale: achieving human scale.
- Empathy: achieving sensory interaction between people and building.

3.1.3. The notion of resources: classical sustainable architecture relies on local materials to reduce the high costs of transportation and preserve resources in every single region's architecture. Each material has certain characteristics: physical, environmental, and aesthetical that needs a special technology and requires certain technical methods that suit its properties. The notion of resources includes the following indicators:

- Locality: using local materials.
- Adaptiveness: compatibility of materials used with surrounding context.
- Compliance: the potentials of materials used to create details.
- Cost: the role of the materials used in reducing construction costs.

3.1.4. The notion of technology: each community had established a specific style of architecture, carried out by their people, commensurate with their environment, customs and traditions, until the twentieth century that witnessed the collapse of cultural boundaries by architectural modernity style. Still remains unique forms and local details in each architecture as a natural product of materials, technology, environment and the culture of people. The notion of technology includes the following indicators:

- Craft: applications of local crafts
- Integration: achieving integration between structure and construction
- Joints: precision in treating joints
- Details: ingenuity in making details

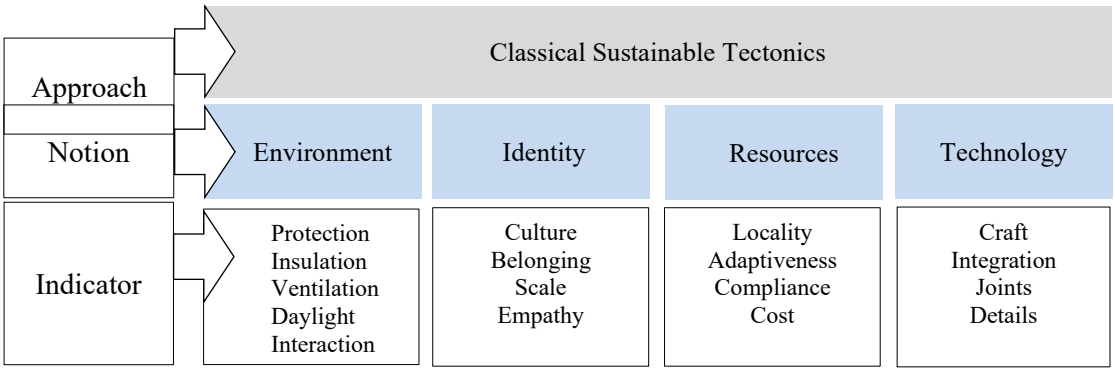


Fig. 4: Framework of Classical Sustainable Tectonics
Source: Author

3.2. Digital Sustainable Tectonics:

Digital sustainable tectonics is a term proposed by the current paper to focus on the generative power of architectural form which can be the basic of achieving sustainable tectonics through the digital manipulation at the initial phases of the design process, thereby creating an integral relationship between sustainability (as a goal) and architecture (as a means). In order to apply logical and scientific methods to achieve sustainability by the concept of digital tectonics, the research proposes a plan of action derived from the application of the main strategies of digital tectonics previously mentioned (generation, optimization, fabrication, and simulation). This plan includes three procedures: 'performance' (representing the visual articulation and resources efficiency), 'industrialization' (representing customization in manufacturing products, and adaptation of BIM and fabrication methods), and 'biomimicry' (representing the simulation of the natural organisms and searching creative solutions in solving design problems). Fig. (5)

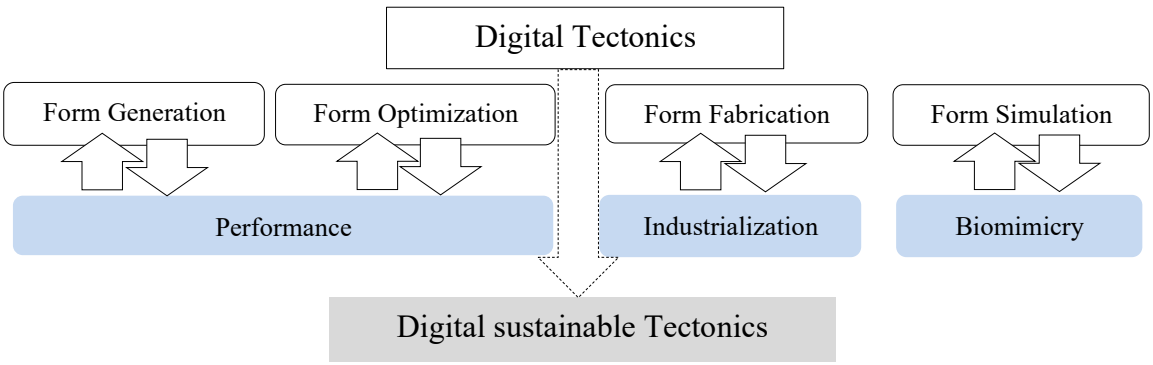


Fig. 5: The interconnection between digital tectonics and digital sustainable architecture
Source: Author

3.2.1. Performance

performance in architecture has become an important factor in the dual relationship of theory and practice. 'Performative architecture' has been established in the architect's consciousness, that his design of buildings should have a positive impact on the built environment to achieve sustainability. The consideration of different parameters in this domain can easily be linked to the digital tectonic architecture. As seen in the overview of the digital architectural styles; the form finding process in term of form considerations as in the topological to metaphoric, and the form finding process in terms of technical consideration potentials as in especially parametric and performative architecture (Kirstine,and Holst, 2009). Performance is classified into two categories: hard performance and soft performance. Hard performance is quantifiable in nature so it makes objective assessments through design. It is classified into: 'structural performance', 'material performance', and 'energy performance'**.** Soft performance is unquantifiable and subjective criterion that depends on particular perceptions. Soft performance

is classified into: 'formal performance', 'functional performance', and 'aesthetic performance' (Atatan, 2018).
Performance takes into consideration the following:

- Social-cultural reflections: the possibility of reflecting the regional and historical identity.
- Articulation: classified into morphological articulation, interior articulation, and articulatory integration.
- -Efficiency: represented in energy efficiency, material efficiency, resources management efficiency.

3.2.2. Industrialization

Industrialization in architecture is the process of producing building in a systematic, serial and standardized way. Industrialization started with the 'Industrial Revolution Building Industry' moved towards mass production that gave the opportunity to produce united, multitude and efficient designs to solve the problems of providing suitable spaces at that time (Beim, et.al. 2010). With the introduction of new digital technologies, emerged the need to develop the production from 'identical' to 'unique' with the same quality. Mass production had to move towards mass customization; the process of manufacturing specific products to satisfy a particular customer's need and achieve quality, flexibility, adaptivity, as well as personalization (Pine,1992).

In this manner, industrialization can achieve sustainable solutions, as argued by the earliest definition of sustainable construction: "Sustainable construction is defined as buildings of high architectural quality taking into consideration people, environment and resources – concerning genesis, use and maintenance" (Beim, et.al. 2010).
The global trend now is to benefit from the modern studies and integrate it with the process of construction which leads to increase the level of sustainability and productivity in addition to provide capabilities to create forms with a cultural expression. This is the key challenge to construct digital sustainable tectonics.

On the other hand, designing the project to be implemented is multidisciplinary; compiles so many information, fields, and different in-charge persons which makes it difficult to control. BIM (building information modelling) is a new methodology that manages all the design process, information, and workers together through the project lifecycle. BIM is a working system responsible to control the entire project's complexity, working with 4-D (the factor of time) and 5-D (the factor of cost). In this manner it differs from other software systems like Revit, Archi-CAD, etc. (archdaily.com).

- Modeling: the need to build projects quicker and smarter, as well as more productive and sustainable is the promising goal. Hence, the key challenge is by adapting the methodology of BIM that makes fabrication opportunities possible.
- Customization: as previously mentioned, tectonics theory is concerned with material, and the emphasis on how the building uses construction and structure to generate a creative production. Since tectonic theory stands against the commodification of architecture, it becomes the model of customization. So, tectonics and customization are two sides of the same coin. Customization in building industry has many factors: specification, economic issues and diversity.

3.2.3.Bio-mimicry

One emerging method is to encourage collaboration between architecture and nature by the strategy of simulation. Digital tools in this case play a significant role in achieving this emerging method. Simulation software is based on analog algorithms found in biological systems, enabling the design process to step toward living architecture. (Benyus, 2002). Simulation as a procedure of digital tectonics to achieve sustainability has an approach in architectural practice known as 'biomimetic architecture' or 'biomimicry'. The origin of the term "biomimicry" derives from two Greek words Bios (meaning Life) and Mimesis (meaning

imitation). The core idea of biomimicry is looking at the nature as a bank of solutions existing in every organism, considering the nature as a" secret to survival".

The procedure of biomimicry is based on the following:

- Analog: the process of analog can either start from design to nature or from nature to design. Design to nature process means identifying the design problem and matching it to the parallel problem in nature in order to get similar solution. Nature to design process means citing solutions from nature. Designers start goggling at the biological systems and its behaviors in order to apply it in the design practices.
- Creativity: the procedure of bio-mimicking in architecture needs a creative thinking and phenomenal perspective. The way of looking at the problem should be from outside the box.
- Environmental Interaction: the procedure of bio-mimicking in architecture can be achieved by following principles of nature including: nature as model, demand of local expertise, maximizing sunlight, adapting form to function, meeting the sufficient needs, recycling the resources, and taping the power of limits (Benyus, 2002).

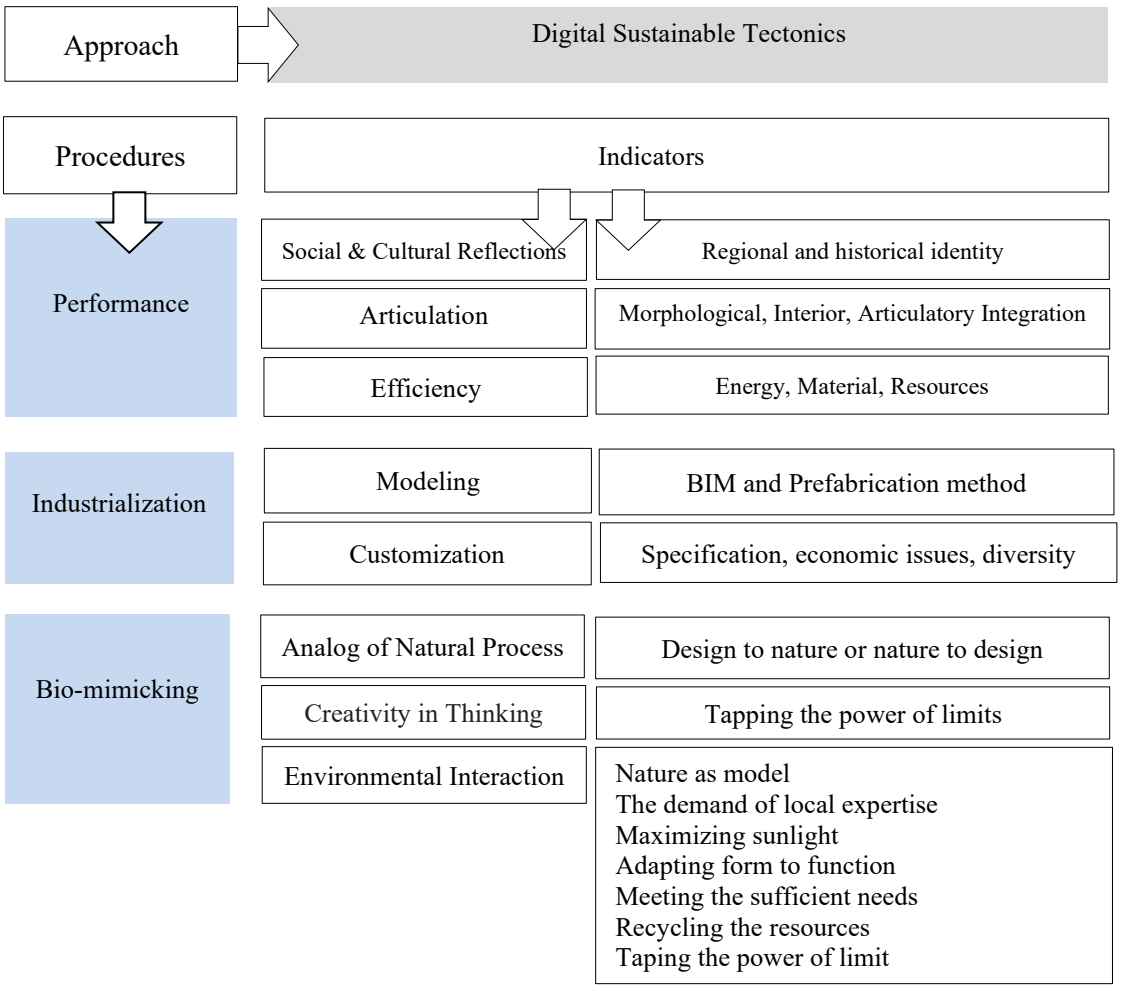


Fig. 6: Framework of Digital Sustainable Tectonics
Source: Author

After presenting the fundamentals and the strategies of tectonics in architecture, both classical and digital, it becomes clear that a formula can be constructed to utilize the tectonic theory in sustainable architecture to form both the classical and the digital sustainable tectonics. A comprehensive theoretical framework has been constructed in which we can define tectonics as a new strategy of achieving sustainability in architecture by enabling different procedures. Many indicators have been extracted to be the guidance in determining the role of tectonic theory in initial phases of sustainable practices. Interaction of tectonic strategies and factors with sustainable dimensions contributes in the construction of the critical argument on the role of classical and digital "sustainable tectonics" in architecture, as shown in the following table.

Table 1: Theoretical Framework of Sustainable Tectonics
Source: Author

The Theoretical Framework of a Submitted Mechanism in Achieving Sustainable Tectonics									
(By: Frampton)		**Tectonic Factors** (pre digital tools)					**Digital Tectonic Strategies** (post digital tools)		
Object	Details	Joints	Material	Structure	Interaction	Construction	Generation Optimization	Fabrication	Simulation
Sustainable Dimensions		Environmental		Social			Economics		Culture
Paper contribution		**New Approach of Distinct Collaboration between the Two domains: Tectonics and Sustainability**							
Strategy		**Sustainable Tectonics**							
Approaches		**Classical Sustainable Tectonics**					**Digital Sustainable Tectonics**		
(By: Author)		**Notions and Procedures**							
The Notion of Environment		The Notion of Identity	The Notion of Resources	The Notion of Technique			The Procedure of Performance	The Procedure of Industrialization	The Procedure of Bio-mimicry
Protection		Culture	Locality	Craft			**Cultural Reflections** Regional and historical identity	**Modeling** 1-BIM Technologies 2-ASTAD Technologies 3-ERCO light	**Analog** Design to Nature or Nature to Design
Insulation		Belonging	Adaptiveness	Integration			**Articulation** 1-Morphological articulation 2-Interior articulation 3-Articulatory integration		**Creativity** Thinking outside the box
Ventilation		Scale	Compliance	Joint			**Efficiency** 1-Energy Efficiency 2-Material Efficiency 3-Resources Management Efficiency	**Customization** 1-Specification 2-Economic Issues 3-Diversity	**Interaction** 1-Nature as model 2-Demand of local expertise 3-Maximizing sunlight 4-Adapting form to function 5-Meeting sufficient needs 6-Recycling the resources 7-Taping the power of limit
Daylight									
Interaction		Empaty	Cost	Details					
Indicators									

4. Methodology

To test the validity of the framework above:

1. A practical study is conducted to verify the role of tectonic theory in achieving distinctive and empathic sustainable architecture. The practical study incorporates the following
   a) Application of classical tectonic indicators on passive sustainable architecture to test their impact on achieving classical sustainable tectonics (Al-Kufa University in Iraq as a case study).
   b) Application of digital tectonic procedures on active sustainable architecture to test their impact on achieving digital sustainable tectonics (The National Museum of Qatar as a case study).

2. A questionnaire is administered to verify the validity of the framework and the extracted indicators. The questionnaire received responses from 40 participants from diverse genders, specialties, and age groups. The purpose of the questionnaire was to evaluate the proposed framework for identifying crucial elements. The questionnaire was created with each aspect's relevance being scaled from 1 to 4, with 4 representing the "very good", and 1 representing "poor", in accordance with the application of the classical and digital sustainable factors and strategies.

4.1. Al-Kufa University (KU)

Al-Kufa University (KU) is an Iraqi university established in 1987 in Al-Kufa city (170km south Baghdad). In 2000, Saher Al-Qaisi, (a well-known Iraqi architect and a professor of advanced urban design and architecture), was chosen to design the whole university as a comprehensive campus of learning. Initially, it included the colleges of medicine and college of education for girls, then it expanded over the years to finally compile 21 colleges and 61 scientific and literary departments. Since Al-Kufa is the medieval city of Iraq (founded in 638 CE) and the first Iraqi Islamic city, it has a historical depth which was taken into consideration as a basic point in the formation of the design concept. The design concept simply combined the heritage with contemporaneity. Thus, two types of envelopes were used to construct the building forms: the first is the brick envelope made of local brick used to reflect the culture and the environment, with Abbasian traditional arches, derived from the city's historical background, to reflect the origin. The second is the white concrete envelope which is the new event jutted from the spirit of civilization, to reflect the purity and modernity. This concept creates an intellectual dialogue between the old and the new, the past and the present. (Al-Qaissy, 2020).

The following axes will reveal the application of classical sustainable tectonics strategies on the selected project.

4.1.1. The notion of environment

- Protection: against the extreme environmental conditions; heat or dust. The protection is achieved by adopting the inward-looking planning which enables the user to move in a protected environment. As well as the use of arcades, trees, and roofing elements that help to optimize the climate.
- Insulation: against the negative effects; noise or pollution. The insulation is achieved by adopting the green belt of trees around the site, and keeping the car park around the site.
- Ventilation: in order to decrease the demand for cooling units, and to reduce energy consumption; ventilation is achieved by adopting the physical rule of achieving air current by creating differences in air pressure. Through the alternation between mass and space, shadow and light, courtyards and narrow paths, differences in air pressure occur, according to the physical rule: the air moves from the high-pressure areas to the low-pressure areas, creating the flow of air currents.

- Daylight: Although all processes are applied to protect from the sun, its light is required because the building activity (studying) occurs in the morning, there is a need of sufficient amount of sunlight to reduce the number of lamps required for lighting. This indicator is achieved by opting optimal orientation and allowing appropriate openness by windows.
- Interaction: although interaction between building and environment is a sensory indicator that is not related to a specific scale, but the clear horizontal design of the university and the ratios between mass and space that determine the containment helped in achieving this indicator.

4.1.2. The notion of identity

- Culture: the campus as a whole reflects the culture of the Islamic city, by applying all the design principles derived from the Islamic architecture and achieving the harmony of the style of the building forms with its urban fabric.
- Belonging: the factor of privacy applied in the planning design, as well as the inward-looking planning creates the sense of belonging. In addition, the campus has many social activities (sports areas, cafeterias, and the central library), which makes it an integrated and comprehensive site.
- Scale: human scale is achieved at two levels: first on the planning level by the integral relation between mass and spaces in order to give the sense of containment, the second on the design level by keeping buildings in horizontal harmony. Human scale allows visual permeability and harmonious urban scene.
- Empathy: Unity, repetition, culturally deep details, horizontal balance, afforestation and human scale are qualities that maintain the sensory interaction between people and the campus buildings

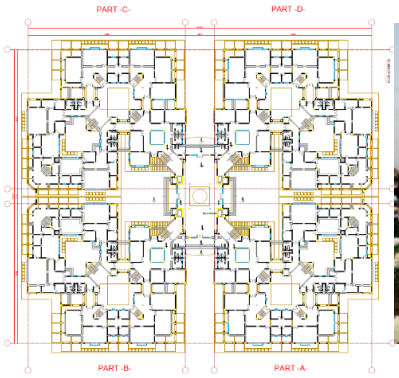
4.1.3. The notion of Resources

- Locality: all the material used were local
- Adaptiveness: as the material used is local, it is compatible with the Iraqi standards, which is based on the adaptiveness of the environmental local conditions.
- Compliance: arches for example were constructed only by the brick without using cast-in concrete to form this shape.
- Cost: Low transportation costs (due to the use of local material) had a role in reducing construction costs. In addition, the adoption of two materials in finishing all the campus facades reduced the opportunities of waste in materials.

4.1.4. The notion of technology

The design of the campus revealed that there is no separation in thinking about indoor and outdoor, form and function, static and movement, mass and space. Everything is thought of as part of a whole.

- Craft: The building concept, location, and the time of execution did not need sophisticated techniques, only local workers who demonstrated their potentials in implementing the most difficult details, under the direct supervision by the designer.
- Integration: because the design process was three-dimensional, the plan reflects the building forms, and the architectural system integrates the structural system.
- Joints: as the design concept is combining the heritage with contemporaneity (which are totally two extreme events), the design relations in treating the joints of the two events were masterful, creating harmony in architectural forms, despite the incompatibility of the two events intellectually.
- Details: architectural details in the implementation had a great role in highlighting the aesthetics of the buildings; the ways of arranging the bricks, the white frame that surrounds the arches, brick decorations, etc.



A-The Notion of Environment
the inward-looking planning, by shaping the courtyards and making the spaces oriented towards it.

B-The Notion of Identity
One of the first peculiarities of building design, which was evident at the level of planning and the level of design. The use of the traditional Islamic architecture thought and features had a role in highlighting the notion of identity

C-The Notion of Resources
local materials had been used as to enhance the design concept and the economic issues.

D-The Notion of Technology
local technology as the basic approach towards building implementation according to the social and environmental conditions emphasized the general concept of tectonics.

Fig. 7: Al-Kufa University \ Classical Sustainable Tectonics
Source: Author

So, the basic notions that were put forward to achieve classical sustainable architecture, and the key-concept of all indicators were based on linking building with its environment. This was invested by the following aspects: building's interaction with all climatic conditions (natural environment), building's connection with the city's identity (cultural environment). In addition, the interaction went further to invest the local materials produced by the environment, as well as the implementation of the techniques and crafts of its inhabitants. By adopting these concepts, the essence of tectonics and sustainability is undoubtedly perceived.

4.2. The National Museum of Qatar

The National Museum of Qatar (NMoQ) in Doha, opened in March 2019, is a dramatic project that evokes the desert in its immortal dimensions and dedicates the history of the country with the spirit of modernity. This 40000 m^2 construction is designed by famous French architect Jean Nouvel. (ICPMA,2018). It includes areas of exhibition, an auditorium with 213 seats, a research center, learning spaces, 2 cafes, 2 shops, a roof-top restaurant, as well as a park with a sculpture garden, a botanical garden, a children's play-ground, an artificial lagoon, and a variety of the facilities. (Bianchini, 2019)

This museum is enclosed by a landscaped park of an 112000 m^2 of area, which is modeled by the landscape designer M. Desvignes. The gently undulating garden features and the native trees and plants have been planned for representing Qatar's history and land. (Griffiths, 2019).

National Museum of Qatar, is the only museum in worldwide, that has obtained the Global Sustainability Assessment System (GSAS) 4-Star rating for design and build certification. In addition, the project has achieved the Leadership in Energy and Environmental Design (LEED) Gold certification as well. Figure (8)

The following axes will reveal the application of digital sustainable tectonics strategies on the selected project.

4.2.1. Building Performance

- Social and Cultural Reflections: The exhibition has been split to 3 thematic areas**,** which have been referred to as (the *chapters)*, which are: Beginning, Life in Qatar, and Qatar's Modern History chronologically depicting the country's history from the pre-historic to modern days. The museum includes a loop path which is 1.5 km long encircling a central courtyard, which is referred to as the Howsh in Arabic. By the end of the tour, the visitor emerges from the building of Nouvel to the historical Palace of Sheikh Abdulla bin Jasim Al Thaani (Griffiths, 2019).
- Articulation:
  - Morphological Articulation: The building built from 539 morphological elements, is a representation of the extraordinary desert rose which have disc-shapes, every one of which has an 87m diameter (Serbedzija, 2019).
  - Interior Articulation: represented by the systematic differentiation of the structural elements to simplify internal arrangement of large spaces, and signifying the occupational distribution by structural logic which is visually accentuated to become perceptually palpable and systematically correlated with an occupational logic (Serbedzija, 2019).
  - The Articulatory Integration: the articulatory integration of the formal and structural consequences as technical requirements is the best solution instead of the attempt of hiding or rejecting them. Tectonic articulation of NMoQ implies that the selected formalism has been derived from a selected engineering logic (Schumacher, 2014).

Through semblance attributes, the setting and arranging of discs were very careful in design and articulation to be mentally captured, this reflects the role of spatial organization physical characteristics of the built environment in human response and interaction to achieve an empathic outcome (Fakhrulddin et.al., 2023). Conscious organization of the building's elements to create an appropriate environment for the activity is a process of transforming space into a place, it is not a simple process, it gives a value to the occupants and their cultures, meaning that the space is a place for its users (Al-Alwan and Aboud, 2010).

Efficiency

- Energy Efficiency: is achieved by adopting the efficient insulation and high-efficiency glazing for the facades, thermal mass for the minimization of the utilization of energy for the purposes of cooling at the interiors. Sensory Units of the CO2 are utilized for the adjustment of the volumes of the fresh air based on the levels of the occupancy. Advanced units of heat recovery re-use the outgoing cool air at the same time as pre-cooling the incoming warm air. In a similar manner, with the use of the approach of the displacement ventilation, the fresh air has been introduced at low levels occupied by people and exhibits whereas upper levels are passively cooled only, thereby decreasing the consumption of the energy. the easy access to the bus stops and the metro stations, the spaces of the priority have been allocated to eco-friendly vehicle types like the electrical and hybrid vehicles
- Material efficiency: In a building that sought to be the cultural and historical landmark in its country, materials used should be sustainable, adorable, and have a great role to keep it alive over the years despite their exposure to harsh environments and climatic conditions (Al-Yaseen et.al., 2020). Material

efficiency is achieved by using environmental products and adopting material recycling methods. With the advent of smart materials technologies, smart materials have been integrated together into buildings to create smart materials systems. These systems work within the built environment to afford better performance to the occupants (Abdullah and Al-Alwan, 2019). Exterior Materials include palm tree, grout, water-proofing membranes, sand, and concrete mixture. Interior Materials include Adhesives, paints, sealants, carpet systems, coatings, composite wood which have been utilized in the museum, were selected taking into consideration their low content of the VOC. (GORD, 2019).

- Resources Management Efficiency: accomplished by enabling the following systems: Irrigation System, Drainage System, Native Flora, Anti- Erosion System , and Other Green Facilities: Low flush sanitary fittings and towers of cooling which is utilized in the conventional cooling systems (GORD, 2019).

4.2.2. Building Industrialization

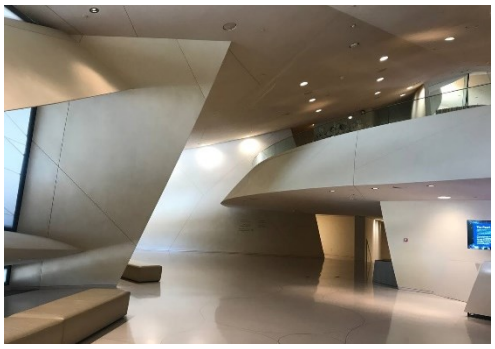
- Modeling: Due to their economic returns, the digital and technical programs have been adopted for: modeling, following up constructional phases and controlling all project parties (clients, engineers, stakeholders, suppliers, etc.). The main digital programming systems that are employed in this project are BIM, ASTAD, and ERCO architectural lighting. (ICPMA,2018).
- Customization: Specification: for the sake of turning this exceptional design to an achievable building, the envelop discs have been planned in a staggered manner, overlapping each other partially. This complicated exterior geometry has been sustained within the building, which has created a distinctive spatial experience. (Serbedzija, 2019).
  - Economic issues Werner has provided 900tons of the ready-mixed mortars and Kimmco-ISOVER 150000m²glass wool for the insulation of this building and its systems of ventilation, air conditioning, and water supply. (Serbedzija, 2019).
  - Diversity: ERCO LED lighting has been utilized as well for the creation of the highly resource-saving solutions of lighting with low generation of the heat (erco.com).

4.2.3. Bio-mimicry

- Analog: As to create an eye-catching landmark, free form structures that are inspired from nature is adopted by using physical or computational models to manage the acting forces of geometries with equal overall potency (Al-Jubori et.al. 2020). The building started (from Nature to design) process. It mimics the desert rose that crystalized naturally at the upper level of groundwater through a series of interactions between minerals present in the water such as calcium and limestone in the sand to form an array of flat plates resembling rose petals (Al-Jubori et.al. 2020).
- Creativity: Nouvel took the 3 important historical glimpses and economic miracles occurred to shake up this overwhelming tranquility: pearl trade and fishing, the discovery of oil, and the discovery of gas, those events put Qatar at a real crossroads transforming it from desert land to a tourist attraction point for each world population. he picked up the form of the desert rose that emerges from the desert and grows progressively, similar to the growing of the State of Qatar (jeannouvel.com).
- Interaction: this indicator investigates how NMoQ interacts with the environment. The main principles of bio-mimicry extracted by Janine M. Benyus are as follows: (Benyus, 2002)

- Nature as a model: the museum represents a dramatic detail in the landscape of Doha; with the curved disks, cantilevered angles, and intersections, which have been inspired from the local desert rose of Qatar.
- The Demand of Local Expertise: Qatar is known for its ancient marine traditions and this museum has celebrated that factor by committing to the preservation and explaining of wooden hand-built (dhows) which once have been the beating heart of Doha.
- Maximizing sunlight: The design of the disks has been made for providing much shade in the extremely hot weather of Qatari peninsula, in addition to being an orientation for the desert landscapes of Qatar (Bianchini, 2019).
- Adapting form to function the building has provided passive shade from sun, which has reduced the sun light gain to the solid as well as the glazed regions, in addition to the provision of comfort for the individuals who move around the building (dezeen.com)
- Meeting the sufficient needs The utilization of the fresh air has been altered for matching the rates of occupancy with the use of the CO2 sensors, with the air recirculated in any possible place and full re-circulation in the case where galleries are not occupied. (Serbedzija, 2019).
- Recycling the Recourses: The NMoQ construction has followed environmentally responsible practices. 98% of wastes, which comprise about 58350 tons, which have been produced throughout constructing, were diverted from the landfills via the recycling and the reusing. (Bianchini, 2019).
- Tapping the Power of Limits With its idea, creation, treatments and details the building tapped the power of limits.

A- The NMoQ (exterior view)
The building's inspiration is from crystal formations of desert roses, it's responsibility for protecting the environment where it exists; according to the highly rated LEED criteria, The use of BIM was also the important factor for the realization of such a vision by its capability of comprehending the complicated grid structure types, and controlling all implementation phases and stakeholders. lead us to conclude that the design enhances the environmental and economic dimension of sustainability.

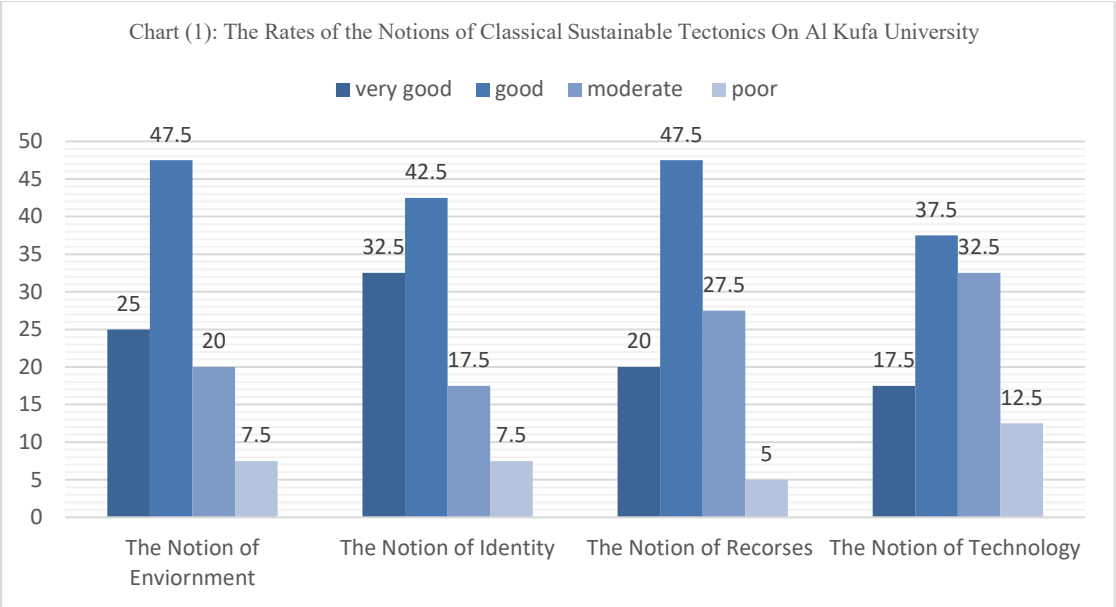


B- The NMoQ (interior view)
The articulatory integration between structural and architectural elements, ingenious systems of energy efficiency, and the cultural reflection of the design concept. lead us to conclude that the interior design enhances the environmental, economic, as well as the cultural and social dimensions of sustainability.

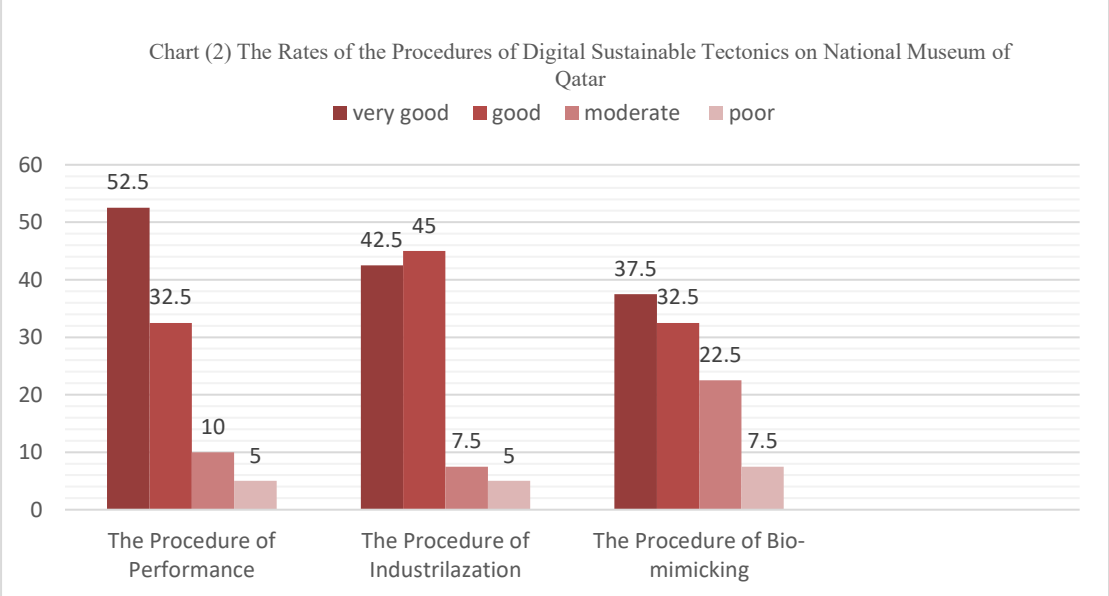
Fig. 8: The National Museum of Qatar \ Digital Sustainable Tectonics
Source: Architect Saad Fadhil

With regards to the procedures that were put forward to achieve digital sustainable architecture, the key-concept of all indicators was based on using digital technologies in all constructional and architectural processes, controlled by architect. Thereby, the most urgent call is to invest the tectonic theory as a new way of thinking at the initial phases of generating architecture, to construct sustainable architecture with technological means and humanitarian impulses.

4.3. Results of the Questionnaire



The notions of environment and identity achieved a better rate in comparison with resources and technology notions. According to questionnaires feedback: the concept of design was more sophisticated than the actual implementation, thus the quality of the design lessened. The project was executed over a long period of time, under different circumstances in Iraq, and the market place in general.



The general rate of NMoQ was very good, in comparison with the rates of al-Kufa University it was advanced because the project is up-to-date and there was a programming system that link the process of design with the process of implementation, also the short period of time between design and implementation.

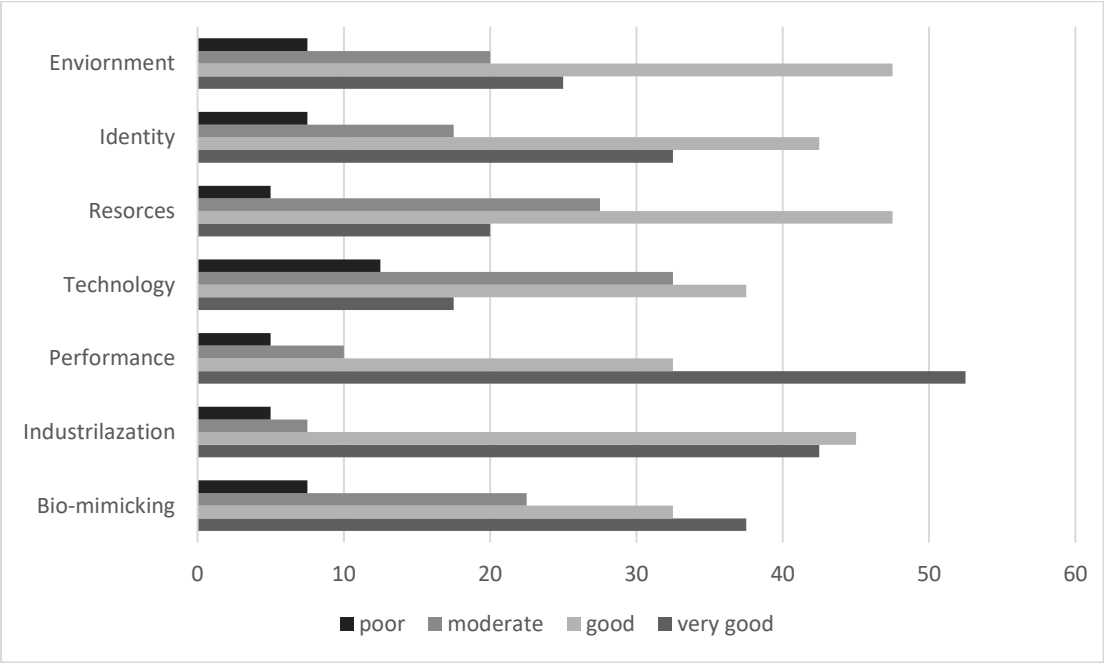
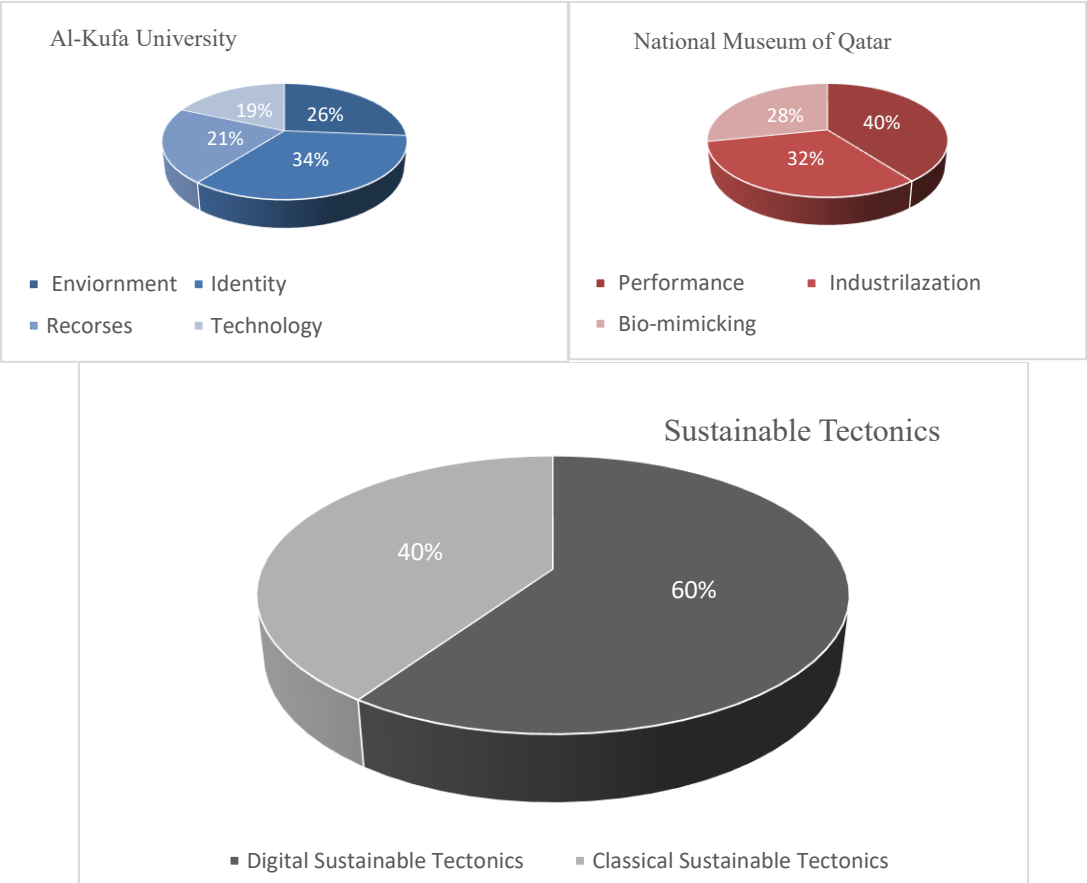


Chart (3) All Indicators of Classical Sustainable Tectonics and Digital Sustainable Tectonics.
This chart combined all notions and procedures to test the validity of classical and digital sustainable tectonics into the selected projects, although the variable rates, all are acceptable.



Charts (4) The Rate of Sustainable Tectonic Factor on both Examples.
By Increasing the insight scope, the previous rates can determine the level of sustainable tectonics in each project, whatever which project was higher, both are achieved the factor of sustainable tectonics in their levels. This was the aim of the paper.

5. Conclusion

5.1. Conclusions of the Theoretical Exploration

- Tectonics is a good means to understand architecture comprehensively as an artistic and technological form. An architect who thinks tectonically will have an insight that makes him think deeply about the building at three levels: production level; the systems level, and the conceptual level. The significant factor of tectonics is creativity; in details, in joints, as well as in the integration of the building systems.
- The research classified it into two approaches: the first is classical tectonics which is the general concept of tectonics developed by adopting the definitions of the most important theoreticians who had different points of view that made the concept encompass several perspectives. The second approach is digital tectonics which is the new version of the classical term; digital is realized as ethereal, absolute and a disregard to the laws of nature, while tectonics is palpable, material and arising as a reaction to the laws of Nature. Digital tectonics requires the limitation of the role of computer tools as to facilitate the design process, not control it.
- This long- established theory has now become used in modern practices, especially in the field of sustainability that was the aim of the paper to find the interrelated relationship between the two fields.
- The research presented "sustainable tectonics" as a new critical approach to develop the ways of producing empathic sustainable architecture by maximizing the value of tectonic theory.
- Sustainable tectonics as a strategy of achieving sustainability is thereby classified by the research into two approaches: classical sustainable tectonics and digital sustainable tectonics.
- Classical sustainable tectonics refers to the passive notions of building design that take the advantages of the local environmental conditions, cities' identity and cultural expression, the local resources and native technique.
- Digital sustainable tectonics refers to the active procedures of producing buildings that take the advantages of computer programs in all phases of the design process and building production. The procedures are: performance (the visual articulation and resources efficiency), industrialization (customization in manufacturing products, and adaptation of BIM and fabrication methods), and biomimicry (simulation of the natural organisms and searching creative solutions in solving design problems)

5.2. Conclusions of the Practical Application

- The domain of classical sustainable tectonics \ Al-Kufa University
  The procedures that were put forward to achieve classical sustainable architecture, the key-concept of all indicators were based on linking building with its environment. This was invested by building's interaction with all climatic conditions (natural environment), building's connection with the city's identity (cultural environment).
- The domain of digital sustainable tectonics \ National Museum of Qatar
  The procedures that were put forward to achieve digital sustainable architecture, the key-concept of all indicators was based on using digital technologies in all constructional and architectural processes, controlled by architect. Thereby, the most urgent call is to invest the tectonic theory as a new way of thinking at the initial phases of generating architecture, to construct sustainable architecture with technological means and humanitarian impulses.

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