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The transformation strategy and its role in forming the structure of future architecture

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ABSTRACT

Nature's strategies and solutions represent a significant and rich source to benefit from in creating an architectural composition that corresponds to its structure, which leads to the emergence of unexpected, vibrant, and constantly changing architectural forms due to the continuous development and progress in technology and science. Transformation is one of the strategies of nature that can be used to form the structure of future architecture, characterized by diversity and continuous formal change. Therefore, this strategy must be studied to create an adaptive architectural structure. The research aims to develop a theoretical framework that explains the role of transformation strategy in forming the structure of future architecture. The study thus reviews the basic concepts of transformation and future architecture. Then it presents the mechanisms to achieve transformation in architecture. Indicators of the conceptual framework of the transformation strategy are extracted from the knowledge provided about it. The conceptual framework represents a tool for enhancing the transformation strategy taken from nature to create innovative future architectural structures that look like living organisms, where they can perform adaptation processes and formal diversity.

Keywords: Transformable Structure, Future Architecture, The Structure of Future Architecture, Transformation of Future Architecture

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1. Introduction

Future architecture is a functional architecture that can transform and respond to changing influences and requirements, whether active or aesthetic [1], and achieving this characteristic in the architecture of the future requires the use of a structure that can adapt, modify and change its shape, as some parts of the system carry out the transformation process while maintaining the integrity and solidity of the structure [2]. Future architecture uses nature as a source to generate its forms, as the study of each of the elements in nature will lead to the creation of lightweight, artistic, flexible, economical, and high-performance architectural structures. And using lightweight and active structural forms such as those found in nature leads to fewer materials, less energy consumed, and an amount of waste [3]. Where the architect resorts to simulating transformation strategies and reactions of living organisms in nature When exposed to environmental changes and trying to transfer them to architecture, where the methods of dealing, reactions, and even the form vary depending on the factor affecting them [4], for these reasons, this research is essential to formulate a theoretical framework for the role of transformation strategy in the future architecture and its application. Future architecture means the architecture that precedes time, as it is an architecture outside the framework of time governing most things, as time has no influence on it and the laws of time have no effect on its products. Future architecture is liberated from stagnation and stability towards dynamism and flow by having behaviors similar to the living organism. It is characterized by a changing structure due to its connection with

technology and science [1]. Future architecture tends to take the natural as a source of inspiration in its forms, by metaphoring from biological structures and systems, in addition to metaphoring from the advanced possibilities of building materials [5], where the designer resorts to nature to take a set of alternatives and solutions for the structural system and try to apply these solutions to the future architecture to obtain innovative and advanced structural systems with new rules in the architectural formation [6].

1.1. The features of future architecture

1.1.1 Dynamism

It is one of the distinguishing features of future architecture, where the use of forms that create the impression of movement and flexibility to express the changes of life and speed, as well as resorting to the use of active structures systems. Future architecture is characterized by instability, a dynamic architecture that simulates progress and technological development [1]. Technology is seen as an engine of change by making things bigger, faster, and more automated and utilized to create dynamic, non-stationary designs through various digital tools [7]. Where the character of instability works to add the property of vitality and activity in the structural system and change the state of equilibrium, and dynamism is achieved in the structural systems through the mechanism of change in the relationships between the elements of the structures or resorting to the function and with the help of digital technologies to produce responsive designs through a series of transformation mechanisms And the change in shape, which contributes to the creation of innovative and unfamiliar structures [8].

1.1.2 Adaptivism

One of the distinguishing characteristics of future architecture is that it is adaptive architecture, where adaptation refers to the ability of architecture to respond to continuous changes and interact with the needs of the user. They are not static but rather active and interactive buildings that are affected by every force and respond to every action. Salvador Dali put forward his vision about future architecture when he predicted that it would have a natural shape and texture and become as if it were part of nature. That adaptation in the future architecture could be internal, meaning that the interior elements of this architecture from ceilings, walls, and services are adapted according to the needs of its occupants in terms of the possibility of controlling spaces that can grow through a set of tissues and particular layers that are similar and identical to the skin of living organisms and the tissues of plants. Or externally adapted to the environment, that is, it works on taking advantage of the heat and natural lighting from the surroundings and controlling it automatically, in addition to having the ability to control the rate of oxygen entry necessary for its users [9]. Where adaptation is one of the best qualities possessed by life forms on Earth, it is an essential element for the survival of species, and transformation in architecture means visualizing the building as no longer a closed system but as a living organism transforming itself to adapt to changing external and internal conditions [10]. The adaptive architecture consists of a structure that can be changed and altered by an external force through the structural system itself, or the transformation process can be done manually [11].

1.2. The definition of transformation

It means the change that occurs at the level of form, where architecture can change its shape and its parts to keep up with the various modifications of the shape according to the changeable structures, and this characteristic is the result of imitation of the processes by which most designs work in nature. In plants, transformation and change processes usually occur, allowing them to bear more than one morphological configuration to fit the surroundings [12]. The imbalance to which the structure is exposed causes a state of turmoil, which makes it compelled to transform, Where the reorganization with a higher level of complexity to produce a new system that replaces the old system, and the transformation occurs through a process known as (emergence) where the change is either part of the system or occurs in The system as a whole (system restructuring) [13]. Ching has pointed out that transformation is based on any organization that can produce new and different systems through repeated manipulations to form unfamiliar structural systems [14].

1.3. The mechanisms to achieve transformation.

Several mechanisms can be depended on to achieve transformation in architectural structures, including the means of concealment (hiding some elements) by covering these elements with reflective materials or trying to make them very thin that it disappears entirely into space, or using diamond structures that transformed the columns to a group of inclined elements that can withstand lateral forces, which reduced the clarity of

structural joints [15]. Another mechanism used to achieve transformation is the manipulation mechanism in the points that make up the structural network, which changes the traditional structure into a completely new one [16]. In addition, the transformation process can be achieved through the use of digital techniques by simulating existing structures in nature to produce new structural systems, as these techniques give many structural possibilities by dealing with structural lines as a set of a mathematical formulas that are manipulated and changed through a set of procedures to produce new formula, by gradually adding or deleting several components of the structural system. That is, the generated model depends on a series of mathematical rules and uses 3D physical modeling as a method to create the shape of the transformed structure from a previous structure (where a set of operations are applied to the structure such as fragmentation, bending, folding, and others to change the shape of the resulting structure), and is also used Animation as a technique for modification to choose the best structural system, and reassemble its elements to transform the structure from one state to another through a series of soft, animated transitions carried out by the computer [17]. Structural transformation strategies are based on a set of significant formality variables, which include; Size, Shape, and Location: Structures that modify their size achieve movement by changing size and proportions, and the structures that limit their shape are in motion while transforming their geometric patterns and modularity. The structures that modify their position achieve movement by moving in space mainly through rotation or deformation [18].

2. The types of transformation

Modification of size, shape, and location results in several transformations that include; Deformation, folding, sawing, retraction, slipping, and rotation. Some structures may share a group of two or more of these types, and these transformations will be explained successively [19].

Deformation means that the structure is changing in a "disorderly" and can be reshaped to its original configuration.

Folding refers to structures that can wrinkle so that they touch themselves, as this type of structure is made of flexible materials.

Diffusion means structures composed of mechanisms that can be compressed away for storage purposes and extended to be ready for use. Retraction means structures that can be pulled back or on top of the other. This type consists of flat solid elements. Slipping refers to structures that move entirely from side to side and are in constant contact with the surface. Rotation means structures or structural components that rotate around an axis [18].

3. Method

3.1. Extracting the theoretical framework

According to the above, the vocabulary of the theoretical framework for the transformation strategy in the formation of the structure of future architecture will be extracted, which includes four main vocabularies, as shown in Table 1.

Table 1. The vocabulary of the theoretical framework of the role of transformation strategy in the formation of the structure of the future architecture

Main vocabulary		secondary vocabulary	Possible values	
First vocabulary	The goal of transformation	keep up with changes	By	The structure is reorganizing itself
				A series of repeated processors
			Level of transformation	At the part level (transformation part of the system)
				At the level of the whole (the transformation takes place in the structure as a whole(
		Adaptation to the surrounding	By creating more than one shape	
			By changing the shape	
Second vocabul	Transformation mechanisms	Hide some elements	covering the elements	
			Use of ultra-thin items	
			Use of diamond structures	
		manipulation	The points in the structure network	

<table>
<tr><td rowspan="3"></td><td rowspan="3"></td><td rowspan="2">mechanism</td><td rowspan="2">The relationships between the parts</td><td colspan="2">Deformation</td></tr>
<tr><td colspan="2">Moving</td></tr>
<tr><td colspan="2">Curvature</td></tr>
<tr><td rowspan="2">Digital simulation of nature's structures</td><td colspan="3">The process of structure</td></tr>
<tr><td colspan="3">The appearance of structure</td></tr>
<tr><td rowspan="8">Third vocabulary</td><td rowspan="8">Types of transformation</td><td rowspan="2">Deformation</td><td colspan="3">Changing the structure is irregular</td></tr>
<tr><td colspan="3">Reformation the structure</td></tr>
<tr><td rowspan="2">Folding</td><td colspan="3">structures can wrinkle</td></tr>
<tr><td colspan="3">The structure contains flexible material.</td></tr>
<tr><td rowspan="2">Diffusion</td><td colspan="3">structure pressure</td></tr>
<tr><td colspan="3">Structure extension</td></tr>
<tr><td rowspan="2">Retraction</td><td colspan="3">Pull the structure back.</td></tr>
<tr><td colspan="3">Pulling structures one on top of the other</td></tr>
<tr><td rowspan="8">Fourth vocabulary</td><td rowspan="8">Properties of the resulting structure</td><td rowspan="6">Structurally</td><td colspan="3">Stabilization Investigation</td></tr>
<tr><td colspan="3">Transfer of loads and Forces</td></tr>
<tr><td rowspan="3">Active Structure</td><td rowspan="2">Improving the performance</td><td>structural efficiency</td></tr>
<tr><td rowspan="2">Achieving adaptability</td></tr>
<tr><td>Adaptation to loads and influences</td></tr>
<tr><td rowspan="2">high flexibility</td><td colspan="2">Use of deformable materials</td></tr>
<tr><td colspan="2">Use of thin materials</td></tr>
<tr><td rowspan="2">Aesthetically</td><td colspan="3">Structural systems with new configurations</td></tr>
<tr><td colspan="3">Variable Structural systems</td></tr>
</table>

3.2. The practical application

In this paragraph, two future architectural examples whose structure was formed using the transformation strategy will be discussed, and the two examples will be analyzed according to the chosen vocabulary (the goal of transformation, the transformation mechanism, the types of adaptation of active, and what the resulting architectural structures are).

3.2.1. Suzanne Lenglen Tennis, 2024

Architect Dominique Perrault has won a competition to design a new retractable roof for the Suzanne Lenglen tennis court at Stade Roland Garros, which hosts the French Open every year. The design seeks to fit neatly into the context, nature, and the city as it opens in the north to the peaks of the Bois de Boulogne mountains. The project represents an opportunity to improve the quality of the existing public spaces, especially the front yard in the south. Once the stadium is covered, the arena will form a protected area ready to operate during sporting events [20]. The purpose of the roof design was to keep the stadium lit and prevent any shadows from falling on it. Once the retractable roof is deployed, the fabric will provide a homogeneous light thanks to the geometrical layout of its segmented surfaces [21]. The other goal is to protect the stadium and all the seats from rain and wind, as the proposed roof hangs over the stands and consists of a moving part made of fabric and a fixed part that provides support for the movable roof and integrates all the equipment needed to fold the movable roof. It has an area of 5200 m^2 [20]. See Figure 1.

Structural description of the project. The roof structure is apparent, lightweight and continuous by carefully assembling the steel elements on the concrete. The roof is fixed on three sides (east, west, and south). That is, it is U-shaped, which opens the view on the northern end, and the eastern and western sides extend to a distance of 87 m which is the side where the folding takes place towards the southern end that contains the tools needed to open the roof when needed and the roof combines the details of a dynamic structure with a living design concept [22], see figure (2). On the other hand, the terraces are surrounded on the side by a mesh

fabric made of stainless steel and fixed in the upper part through the longitudinal beams, and in the lower position, it is set on the existing concrete supports [21]. The construction system for the steel structure is mainly based on bolted assembly. The movable roof (folded membrane) consists of 21 units of V-shaped tensioned fabric fixed between cables, with a total area of 4800 m^2. Each unit is about 5m wide and 44m long. When the roof is deployed, the cables will be stretched to absorb rain and wind loads, and there is a movable beam at the northern end of the retractable roof to lead it during the folding process. The fabric proposed for the roof is PTFE (also called Teflon), a high-strength fluoropolymer fiber. This material was selected for its particularly favorable technical qualities, including low maintenance, durability under repetitive folding motions, and preservation of its mechanical properties in cold weather. It has high durability and a much longer life than traditional fabrics and is characterized by being transparent and low maintenance [20].

3.2.2. Vastetas travel center, 2021-2025

Bjarkelngels Group (BIG) has revealed the final design of the Vastetas Travel Center for Public Transport. The project consists of a bus stop, travel services, taxi areas, commercial areas, restaurants, offices, and exhibition spaces. The project is designed to integrate the fast flow of travelers and the slow flow of visitors, providing access for all [24]. The project is a bridge over the train tracks that reconnects two areas of the city separated by train tracks [22]. The 16,963 m^2 project will be covered with a large roof under which the entire city infrastructure will come together in one landscape that becomes a dynamic urban node and a visual landmark that redefines the city's infrastructure. Construction is scheduled to begin in 2022 and be completed in 2025 [23].

The project eliminates the boundaries between indoor and outdoor spaces through long curved glass facades, ensuring light and openness to the edges of the building, and the active facades increase the sense of security. To allow air to circulate and light to enter, the Bjarkelngels group cuts the roof in a zigzag from one side to the other [26]. The center will have public balconies surrounding the travel hub and create natural connections whereby visitors and locals can enjoy meeting spaces, sit and rest in the sun and observe the city [23], see Figure 3.

The floating roof (as a lightly layered rolling cloud) or (in the form of a handkerchief attached to its corners) is designed to protect travelers and the landscape. The raised corners of the roof structure represent the most critical input, and a zigzag line of load-bearing elements crosses the roof. It connects the columns lining the perimeter, which frees the building from the internal columns. The same line cuts the openings in the ceiling surface for the passage of ventilation and natural lighting [27]. The roof consists of aluminum roof panels that contain a group of integrated solar cells and several primary and secondary bars of zigzag shape, under which there is a roof composed of curved wooden slats, which rests on several vertical tapered pillars, where it takes only the vertical loads. At the four corners of the roof, the columns perform the task of transferring horizontal and vertical loads after their dimensions are determined. The zigzag line in the ceiling gives a flag-like appearance accentuated by the smoothly curved wooden slats [25], see Figure 4.

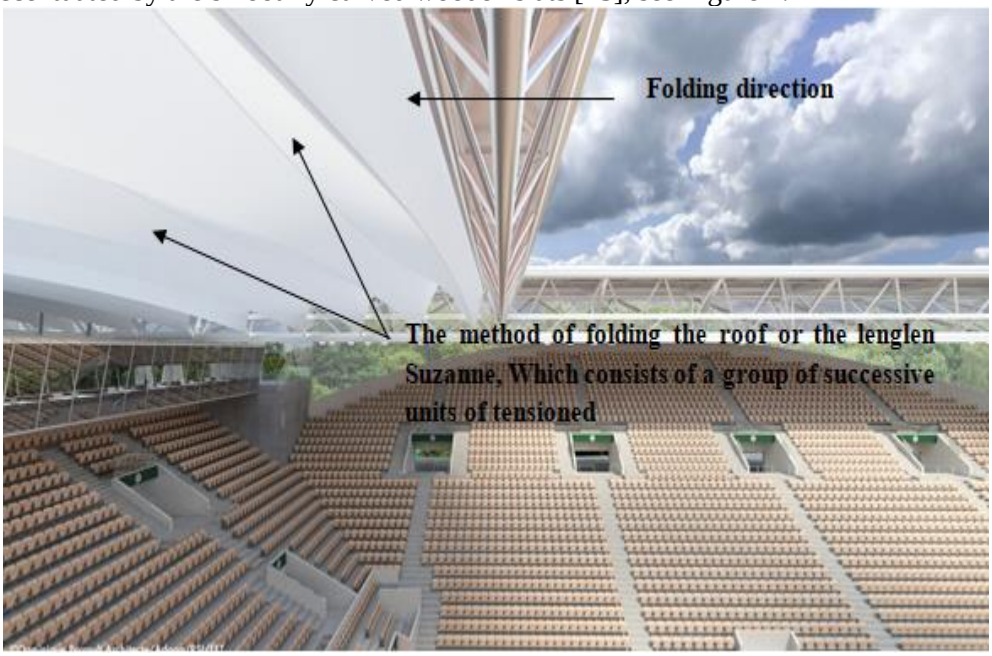

Figure 1. The roof of the Lenglen tennis court in France shows how the folding roof opens and closes [28]

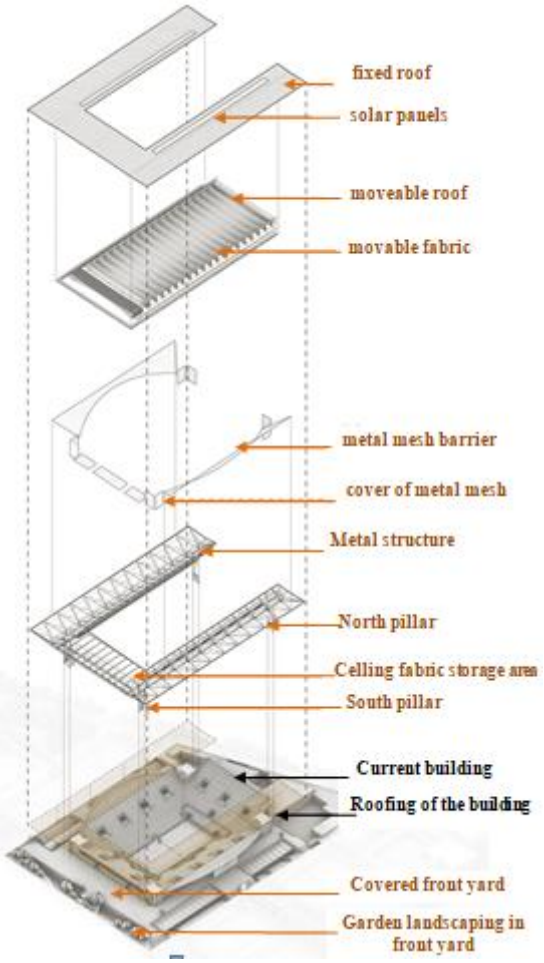

Figure 2. Shows the structural details on the roof of Lenglen tennis court [28]

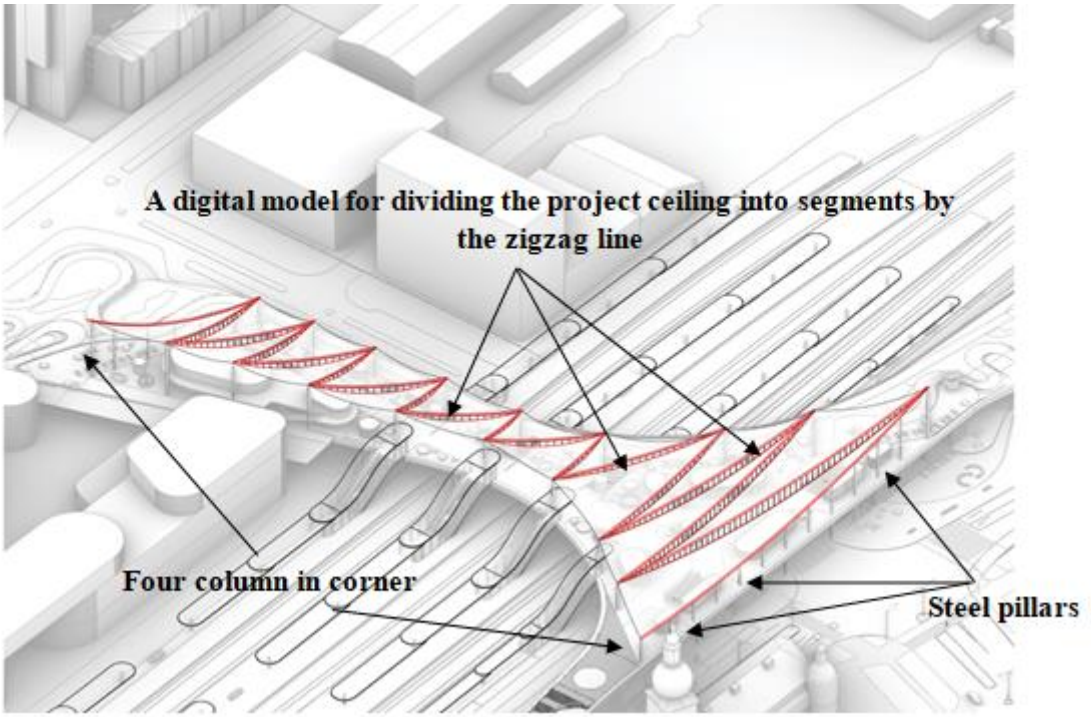

Figure 3. Shows the digital model of Vastetas Travel Center [25]

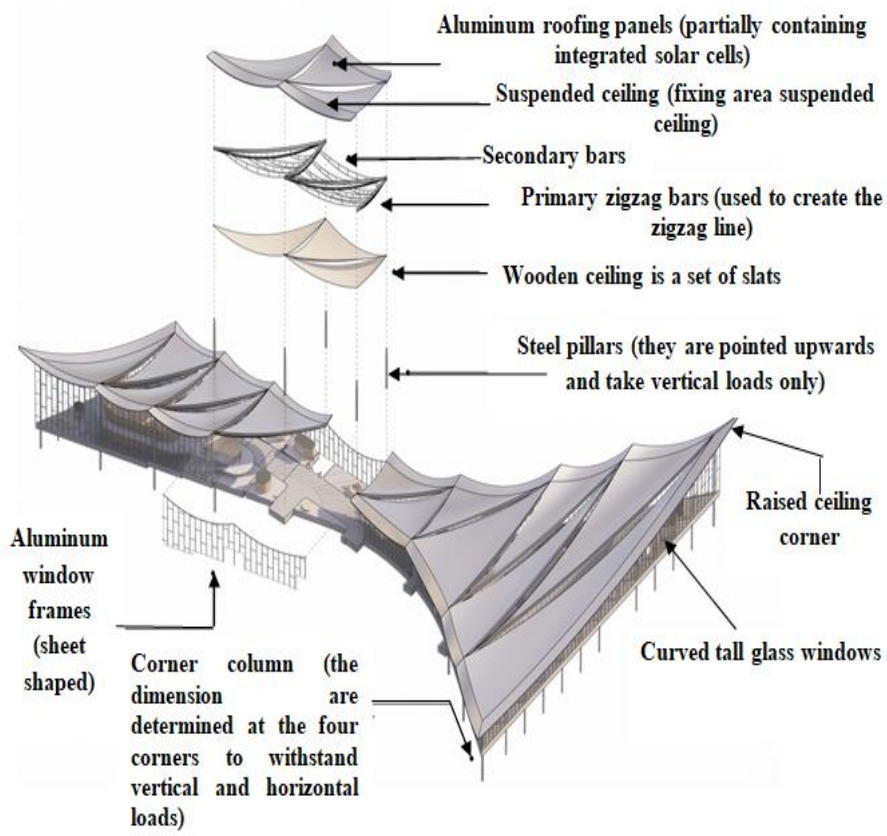

Figure 4. Shows the details of the structural system and components of Vastetas Travel Center [25]

4. Results and discussion

Table 2 represents the analysis form for the variable verification values of the selected projects, which means (1) the value is achieved, and (0) the value is not achieved.

Main vocabulary	secondary vocabulary	Possible values		Symbol	Check Value 1	Check Value 2	Possible value ratios	main vocabulary
The goal of transformation X	keep up with changes X1	By	The structure is reorganizing itself	X1-1	1	0	50%	**%57**
			A series of repeated processors	X1-2	1	1	%100	
		Level of transformation	At the part level (transformation part of the system)	X1-3	1	1	%100	
			At the level of the whole (the transformation takes place in the structure as a whole(	X1-4	0	0	0%	
		The sum percentages of achievement in the secondary vocabulary		**%63**				
	Adaptation with the surrounding X2	By creating more than one shape		X2-1	1	0	%50	
		By changing the shape		X2-2	1	0	%50	
		The sum percentages of achievement in the secondary vocabulary		**50%**				
ati on me ch	so me ele me	covering the elements		Y1-1	0	0	0%	**53 %**
		Use of ultra-thin items		Y1-2	1	1	%100	

		Use of diamond structures			Y1-3	0	0	0%	
		The sum percentages of achievement in the secondary vocabulary			**%33**				
	manipulation mechanism Y2	The points in the structure network			Y2-1	0	0	0%	
		The relationships between the parts	Deformation		Y2-2	1	0	%50	
			Moving		Y2-3	1	0	%50	
			Curvature		Y2-4	1	1	%50	
		The sum percentages of achievement in the secondary vocabulary			**50%**				
	Digital simulation of nature's structures	The process of structure			Y3-1	1	1	%100	
		The appearance of structure			Y3-2	0	1	%50	
		The sum percentages of achievement in the secondary vocabulary			**%75**				
Types of transformation Z	Deformation Z1	Changing the structure in irregular			Z1-1	0	0	0%	**%38**
		Reformation the structure			Z1-2	0	0	0%	
		The sum percentages of achievement in the secondary vocabulary			**%0**				
	Folding Z2	structures can wrinkle			Z2-1	1	0	%50	
		The structure contains flexible material.			Z2-2	1	0	%50	
		The sum percentages of achievement in the secondary vocabulary			**%50**				
	Diffusion Z3	structure pressure			Z3-1	1	0	%50	
		Structure extension			Z3-2	1	0	%50	
		The sum percentages of achievement in the secondary vocabulary			**%50**				
	Retraction Z4	Pull the structure back			Z4-1	1	0	%50	
		Pulling structures one on top of the other			Z4-2	1	0	%50	
		The sum percentages of achievement in the secondary vocabulary			**%50**				
Properties of result structure L	Structurally L1	Stabilization Investigation			L1-1	1	1	%100	**%81**
		Transfer of loads and Forces			L1-2	1	1	%100	
		Active Structure	Improving the performance	structural efficiency	L1-3	1	1	%100	
				Achieving adaptability	L1-4	1	1	%100	
			Adaptation to loads and influences	By changing the shape	L1-5	1	1	%100	
			high flexibility	Use of deformable materials	L1-6	1	0	%50	
				Use of thin materials	L1-7	1	0	%50	
		The sum percentages of achievement in the secondary vocabulary			**%86**				
	Aesthetically L2	Structural systems with new configurations			L2-1	1	1	%100	
		Variable Structural systems			L2-2	1	0	%50	
		The sum percentages of achievement in the secondary vocabulary			**%75**				

The application results showed a discrepancy in the percentage of vocabulary achievement, as the vocabulary of the properties of theresulting structure achieved the highest rate, 81%, the transformation

goal reached the second highest percentage, 57%, and the transformation mechanism achieved 53%. In comparison, the types of transformation gained 38%, the lowest completed value, as in Figure 5.

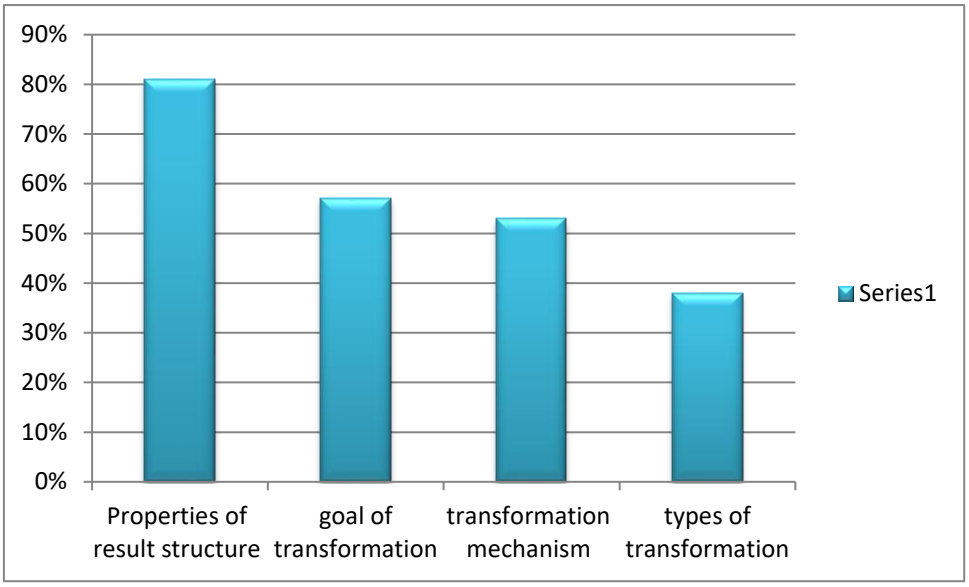

Figure 5. It is a graph showing the results of the practical study of the vocabulary of the transformation strategy and its role in forming the structure of future architecture

5. Conclusions

Future architecture is defined as the architecture that preceded its time due to the continuous development and its connection with the changing modern sciences, an architecture that has no end, a constant architecture that does not stop generating new trends, and the form in it is liberated from all laws towards the strangeness. The structure of future architecture responds to the tremendous developments in technology and construction.
Future architecture, to be existing and possible, needs an active structure that can reorganize itself, its shape, and the locations of its elements through the use of the transformation mechanism represented by manipulating the relationships between its components, which leads to the formation the future structure that can keep pace with various formal changes. The transformation strategy represents one of the strategies resulting from imitation of the processes that occur in nature, where transformation happens in plants to face external conditions and influences through processes of form change. Transformation mechanism means the stages the facility goes through until it reaches its final state through a series of regular treatments of the elements of the structure and by employing digital technologies. Future architecture is characterized by dynamism and adaptation to external conditions, and to achieve these features requires the use of a structure that can carry out processes of change and formal diversity using a set of multiple transformation mechanisms, all of which lead to obtaining unique and unfamiliar future structures. The transformation strategy is used to form future architectural structures, which can accommodate the various changes that the structure is exposed to throughout its existence without causing any damage to the integrity and solidity of the structure when performing reactions and behavioral response processes by using several different mechanisms. Digitally simulating nature structures represents the most used way to transform architectural designs by generating a set of structural possibilities and taking advantage of the mathematical formula through which modifications are made to the structure. The architectural structure resulting from the transformation strategy is characterized by being an active structure with high flexibility and aesthetic value because its forms are variable and unstable. The structure is transformed from one state to another through a series of soft transitions. The use of the transformation strategy in shaping the structure of the future architecture, whether at the level of the whole or the level of the part, will lead to the achievement of integration between the architectural form and the structure and give the structure a character of dynamism and complexity, and lead to the emergence of a new behavior of the elements or relationships between it.

6. Recommendations

Investing in the transformation strategies and their principal and secondary vocabulary that the research has reached as a tool for shaping the structure of future architecture to achieve unique architectural designs that go beyond traditional contexts and be more like a living organism. Resorting to inspiration from nature when designing future architectural structures due to nature's ability to carry out transformation processes to face external influences and withstand various changes. Benefiting from the development of digital technologies and mathematical formulas to achieve transformation in architectural structures.

Declaration of competing interest

The authors declare that they have no known financial or non-financial competing interests in any material discussed in this paper.

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