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Quantitative Evaluation of the Adaptation Flexibility in Intelligent Architecture Systems

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Abstract

Adaptation is a normative practice in the human world, but adaptation is often forced due to undesirable external change, as systems (functional, structural and aesthetic) play an essential role in the adaptation of the building through adoption of intelligent design and use of technology with the aim of improving building and making it a part of its urban environment (Social, economic, physical ... etc.).

The research problem lies in the fact that most modern buildings are separated from their surroundings, which led to the emergence of unique and distinct structures from the context, and systems intelligence became represented in smart technologies and systems, as buildings and user behaviors became subject to the control of the machine, and at the same time the continued existence of traditional buildings. With integrated intelligent design systems, and in depended on that problem, the research hypothesis was determined, which was (the building's adaptation is related to the degree of flexibility available in the architectural system and the integration of architectural systems together according to the passive and the active strategy for both micro and macro levels).

The research aims to provide an integrated measurement approach that combines the quantitative approach that depends on mathematical equations and formulas, and qualitative (analytical) approach represented in an integrated theoretical and practical framework that measures the indicator of flexibility of adapting intelligent systems in a group of selected samples. Through this, it was concluded that the buildings are adaptive when they combine design and technical intelligence and rely on both passive and active strategies in a balanced method and according to the influence, the nature of the system and the integration of systems, or at least the integration of two systems.

Keywords: *Adaptation, Smart Systems, Intelligent Systems, Passive Strategies, Active Strategies.*

1. Introdction

Architecture discovers the hidden potential of intelligent systems in creating a new architectural identity that defines a vision for the future by contextualizing and understanding projects and their fields, and integrating them with smart technologies as it is not just an architecture that responds to or adapts to changing conditions. On the contrary, this architecture is based on the construction of relationships between built components and secondly, on the construction of relationships between people and those components [1].

In Runner's literature, "he points out that adaptive intelligent architecture is the result of integrated, flexible forms and integrated systems that are able to adapt to changes and respond to users and the environment, as adaptation is within the framework of the flexibility of systems (functional, aesthetic and structural) integrated and the amount of change that can be subject to it , the possibility of development and renovation, in addition to that, the social and environmental systems cannot be considered in the absence of each other, but must be understood as interdependent with systems"[2].

The ideas and orientations of flexible system adaptation are formed towards many areas, including those related to the environment and context, including the function, and among them the importance of flexible systems to achieve adaptation, which focuses on studying the research by activating the passive and active strategies that take into account the user and the environment and benefits One of the possibilities offered by modern

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technical development is to improve the function of the building and to adapt to physical and spatial changes[3].

Directing systems in a way that provides flexibility in responding to change, with a focus on providing the element of intelligence in design to achieve adaptation. It does not consider intelligence in terms of technology but rather how systems are integrated by design, as the focus is on keeping flexibility[1].

Achieving the flexibility of harmony between design intelligent systems and technical smart systems, is a special focus of research and includes the impact of the external environment of the building up to the internal spaces and the method of using modern technologies to be integrated with the building design systems in order to achieve a flexible and adaptive architecture.

Translating flexibility in this research into indicators that are measured. So the flexibility index is a partial measure of adaptation. Therefore, any measure of flexibility must reflect potential because the amount of flexibility is relative, not absolute. This study aims to define an integrated framework for flexibility indicators in intelligent architecture systems with an integrated measurement approach that combines the quantitative approach that depend on mathematical equations and formulas, with the qualitative (analytical) approach.

2. Intelligent system in architecture

The Intelligent architectural system is a group of basic building systems consisting of a group of other sub-systems designed to create a dynamic and responsive architecture that provides each inhabitant with productive, cost-effective and environmentally approved conditions through continuous interaction between its basic elements (functional, structural, aesthetic) with smart technology systems (automation , control, response) to achieve compatibility efficiently with changes in the surrounding environment and meet the requirements of the occupants and taken control and response systems and methods as a basic principle [4].

The concept of systems intelligence is characterized by a degree of complexity as it is determined by the structure, patterns of relationships, links and constraints between systems, and on the other hand, Intelligent systems are characterized by a design style, where complex aspects and dynamic systems can be controlled, to achieve adaptation and functional diversity inspired by the vitality, as building systems follow methods and mechanisms and different fields, principles, patterns and strategies[5]. So one of the most important principles to be considered is to meet the specific needs and desires of users. While the level of systems integration and adaptation characterizes intelligent buildings, and this is according to the relationship between systems [6]. As shown in Figure (1).

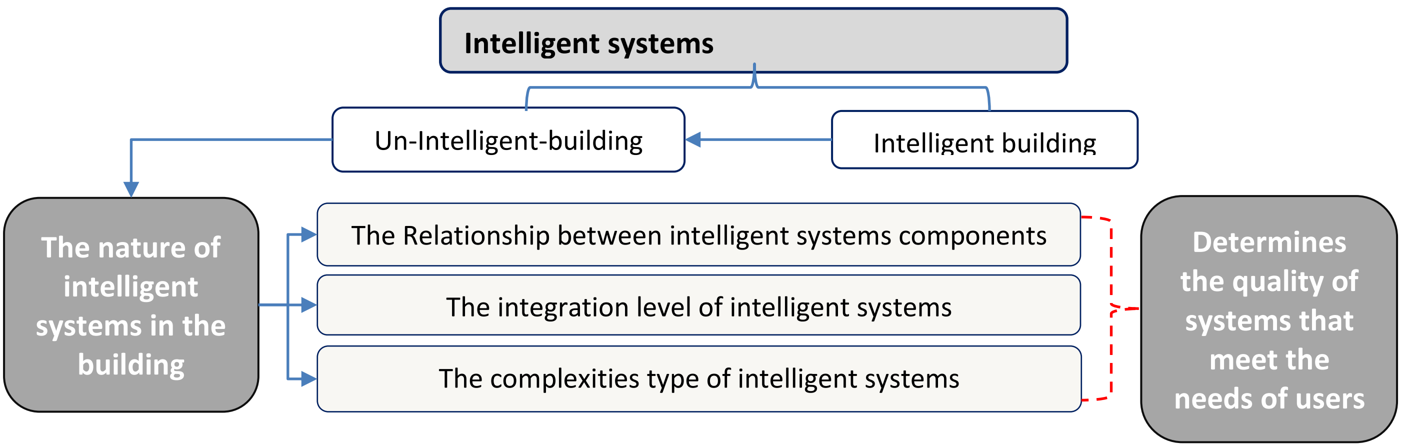


Fig 1: Explains the basic principles of intelligent system in the building.

Intelligent systems are employed by integrating passive - and active strategies to increase the building's ability to cope with various changes, increasing the building's ability to achieve adaptation [7].

Passive strategy: One of the most important strategies that take into account the building design environment and the characteristics required to form the building, since each unique site has its own, passive -design strategy in terms of (orientation of the building, entry of natural lighting, appropriate materials for the building, appropriate shading methods) to improve The performance of the building, with the ability to absorb technological development and the appropriateness between functions and activities, taking into account the environmental and functional conditions of buildings[8].

Active strategy: The active strategy is represented by the secondary systems to achieve the adaptation of the building and raise the efficiency of performance, and among these means (various operating techniques, air conditioning systems, fire protection systems, lighting systems, deception systems) [9].

3. Flexible Architecture

Generally, "flexibility" refers to physical change, modification, and adaptation. Flexibility can be incorporated into architecture through the ability to change the size or reuse of spaces up to the structure of the building.

The ability to keep the building fit for purpose with the ability to diversify functions, continuity and permeability of building blocks and layers, and the ability to keep pace with technological development to meet the evolving needs of the building context efficiently, and thus increase its coherence with its surroundings [10].

The expression “flexibility” entered the field of architectural terminology in the 1950s, with Walter Gropius declaring that “architects must imagine building as a vessel for the flow of life that they must serve” [11].

Flexible buildings require a design that is shaped according to the requirements of the present with potential changes in the future, and one of the most important factors that characterize flexible architecture is adaptation, where adaptive buildings are created to accommodate different functions, determined by the activities of users for the purpose of achieving the goal of the building and employing it to meet all the different uses, and in Most adaptive flexible buildings use the open system, as it works to achieve permeability and continuous communication for the building, and this determines the scope of adaptation[12].

3.1 Adaptation Scope

The scope of adapting intelligently designed buildings depends on the integration of systems and the changes that occur to the building and is on two levels, macro level represented by the radical change in the building and is on a large scope, which includes spatial and structural modifications on a large scope so that the use is changed or the capacity is reduced or increased [13], the micro level is represented in the degree of change on a small scale, as the activities are combined with appropriate functional improvements and extensions in the structural system on a small scope [14].

3.2 Adaptation Actions

After reviewing the strategies and the scope of adaptation in intelligent systems, the applied actions in building systems will be discussed, as these actions represent a set of organized steps that must be taken to achieve adaptation to the needs of users and smart technology and its developments to create intelligent environments for the occupants of the building, as these actions is divided according to the systems (functional, structural and aesthetic [15], as the integration of adaptive actions within building systems is dependent on adaptive strategies derived from the integration of the passive and active strategies and on the macro and micro levels, including (physical strategies directed to work within architectural systems at the micro level, strategies, spatial orientation and orientation towards the macro level). Shown in the table (1) [16].

Table 1 Adaptation actions within the building systems and scope.

Main strategy	Minor strategy	Adaptation actions in architectural systems	Adaptation systems			Indicators
			aesthetic system	structural system	Functional system	
Overlaying passive and active strategies	physical strategy	Overlapping ancient and modern styles in a contemporary design language	●	●	●	extension
		Compatibility between the plan and building mass	●	●	●	
		The pattern of the constructive effect on the resulting architectural formation	●	●	●	self-similarity
		Using technical equipment with sufficient capacity to support more uses	●	●	●	Technical diversity
		The interaction of building systems with changes (structural, spatial, physical)	●	●	●	Change
		Controlling future changes to the spaces of the building		●	●	
		Increasing the envelope dynamism towards external climate influences	●	●	●	
		Basic structure design to be divisible		●	●	
		The possibility of changing structural elements between spaces and installing them in a simple way to meet the changes of function		●	●	
	spatial strategy	Symmetrical and parallel floors are theatrically and dynamically arranged around the central courtyard	●	●	●	permeability
		Fit the dimensions of the internal spaces and their function		●	●	
		Structural or functional extensions by adding new building components and structures	●	●	●	extension
		The diverse functional distribution of spaces in a way that promotes centralization		●	●	permeability
		Transparency and openness of spaces to the city		●	●	Transparency
		Spatial adequacy and functional correlation with surrounding functions		●	●	spatial organization
		Integration of the envelope with the structural system and compatibility with the context	●	●		extension

3.3 Flexibility Indicators:

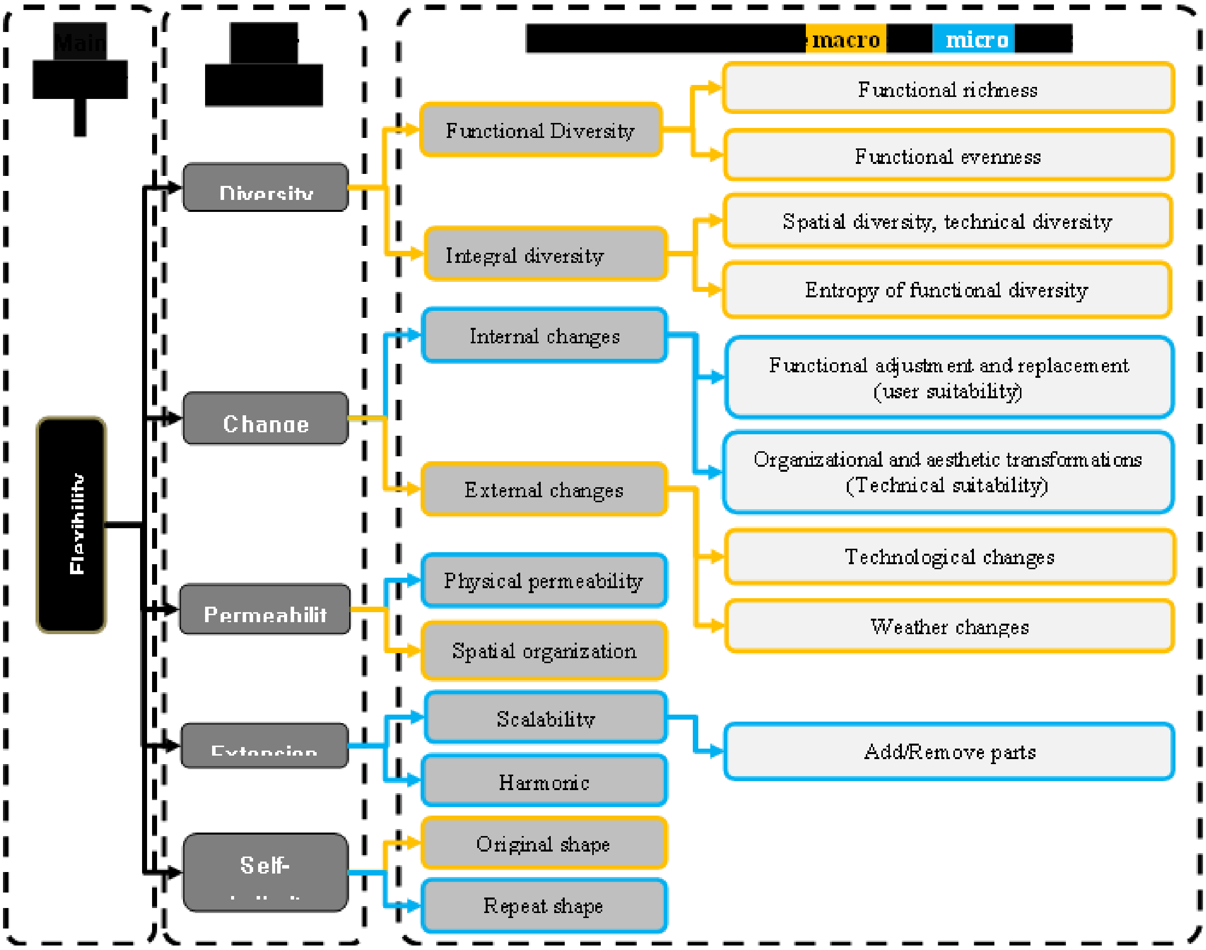


Fig 2: Reviews the flexibility indicators to achieve spatial adaptation in intelligent architecture systems.

4. Methodology

4.1 Measure Indicators

- **Measuring the flexibility of functional & structural system (diversity index) .**

<u>Functional diversity</u>: The diversity can be measured and determined by adopting the biodiversity index, as it can be measured by the number of different types of function and their relative frequency, at all levels of the building hierarchy. Diversity is measured through the two diversity indicators, Shannon diversity index (H) (used to measure the flexibility of functional system diversity/macro level), Simpson's diversity index (D) is used to measure the flexibility of the diversity of the aesthetic system (building envelope / micro level) [17].

The diversity indicator takes into account the number of similar species (richness) and their relative abundance (evenness). To measure the macro level of the functional system, the diverse range is from 0 to 1, and indicates high scores (close to 1) indicate low diversity and low scores (close to 0) indicate high diversity.

It is measured according to the following equation of Shannon Diversity Index (H)[18]:

Diversity = Richness + Evenness

$$D = S-1/ \ln N + H' /H_{max}$$

$$H' = - \Sigma [(pi) \times \log (pi)]$$

$$H_{max} = \ln(S)$$

D = functional diversity , Σ = sum, E = functional equivalence , R = functional richness , S = number of species

Functionally similar, N = total number of species, H'= Shannon Index, H max= Maximum Diversity possible

Pi = functional gene (Various function)

As for the diversity index in Simpson, it measures the micro level of the aesthetic system (building envelope) represented by the adaptive elements in the facades, as the low ratio of diversity indicates the dominance of one species.

The quotient of diversity resulting from the summation of abundance and efficiency depends on the fact that the smaller the ratio indicates the dominance of a particular functional system, and the higher the ratio, the higher the sum, indicating that the building fulfills more than one different function [19], the mathematical relationships of the diversity index. It is measured according to the following equation of Simpson's Diversity Index (D)[20]:

$$D = 1 - [\Sigma (n / N)^2]$$

D = diversity, Σ = sum, n = total number of adaptive elements of a given type, N = the total number of all kinds of adaptive elements

The result of the quantification of the diversity index is as follows:

D=1 or more is very poor diversity, D = 0.7 ~ 0.8, is relatively weak, D = 0.468 ~ 0.694, diversity is equal

D = 0.312 ~ 0.468, the diversity is good, D = 0 ~ 0.312, the diversity is excellent

Integrated Diversity: Based on the levels of biodiversity, three levels of integrated diversity have been created, including the genetic element (a dynamic mechanism), the image element (system formation) and the surrounding element (space environment). It is architecturally simulated as three sub-systems of integrated diversity, including the entropy of functional diversity (functional system), systems intelligence (concerning the extent to which the two strategies are integrated and effective in the building) and spatial diversity (specific to the spaces of activities and uses in the building (a structural system)), and it passes The building is a continuous dynamic process represented by a complete life cycle of systems to interact and integrate with each other [21].

Entropy is measured by the total number of functions in a building and how diverse those functions are. It is calculated according to the following equation [22] :

$$ENT = n /N \ \Sigma \ pi \times \log pi$$

ENT = functional diversity entropy, N = total number of function in the building, Σ pi × ln pi = functional diversity

Spatial diversity is measured by the ratio between the areas of similar job spaces to the total area. It is calculated according to the following equation [21]:

$$HS = 1 - \sum (Ai/TA)^2$$

HS = Spatial Configuration Diversity, Ai = Area of Spaces with Similar Functions, TA =Total Building Area

While the smart building quotient is calculated through the ratio between the use of the passive-strategy to the active, and its ratio range is between (0 to 1), and whenever the building is dependent on the combination of passive - strategy The active value is estimated at (0.8 to 1), and the more the building depends only on the intelligence of the technician and the control mechanisms, its value is (0) because the building is considered as a machine [23]. It is calculated according to the following equation:

$$BIQ = Q R_1 / Q R_2$$

BIQ = Build intelligence quotient, $Q R_1$ = design intelligence ratio, $Q R_2$ = Technical Intelligence Ratio

The three indicators link a symbiotic relationship, and the entropy has the greatest influence in this relationship. The lower the ratio, the integrated diversity.

- **Measuring the flexibility of systems adapting to change (change index).**

Changes in building use are the main motives of adaptation; however, there are other external factors, such as rapid developments in technology, environmental conditions and climate change [24].

While the change can be unexpected or resulting from a modification in the organization of the building. Some of these changes are in organizational processes, including (changes in space planning or changes in function) that arise from the need to improve the performance of the building in all its dimensions in terms of [25].

The measure of change is qualitative by way of analyzing the characteristics and the system subject to change (structural, functional, aesthetic) by identifying (motivation, response method, adaptive scale, and adaptive intelligent element), as follows:

Impulse: The reason behind the change can be (climatic conditions, changes in technology, functional reasons)

Response Method: The resulting situation, which changes over time.

Scale of Adaptation: The adaptation is a response to circumstances and is either at the macro level or it can be at the micro level.

Responsive Intelligent Adaptive Element: either mechanical, pneumatic, hydraulic or material-based.

• Measuring the flexibility of a structural system (permeability index).

Permeability in adaptive architecture represents the quality embedded in architecture, including physical permeability and includes two important parameters that can be used to measure interface permeability [26]:

Accessibility (interpretation of the relationship between time and movement)

Vision (interpretation of the relationship between space and time)

As it is possible to take accessibility versus vision together to measure the degree of physical permeability of the building at the micro level, it represents a tool for studying the relationship between "inside with outside", "outside with outside", and "outside with inside" and it organizes the space shape of the building, as in the following equation[27]:

Permeability = Accessibility + Visibility

Its measurement depends on the criteria shown in the table (2) [28].

Table 2: shows the model for measuring the basic elements of permeability.

Element	Accessibility	Visibility
Concrete wall with limited size openings (windows and doors)	High (natural force) Low (human flow)	Moderate (out-in) Low (in-in)
Glass wall with holes	High (natural force) Moderate (human flow)	High (in-out)
Glass wall (reflective, triple combination, double glazing).	High (natural force) Low (human flow)	High (in-out) High (in-in)
Brick wall with limited openings	Low (natural force)	Moderate (out-in)
The concrete structure that is used to define the yard	High (natural force) High (human flow)	Low (in-out) High (out-out)
roof with slots	High (natural force)	High (in-out)
open system	High(human flow)	High(in-in)

The adaptability of the spatial configuration of the building is assessed by making a spatial map of the building plan, this map contains intersecting vertices in the form of a letter (V) and connects the vertices with paths that connect the vertices with each other and represent the depth between one space and the other, as the lowest depth is the highest permeability [29].

$ATD_{less\ p} = 2v^2 - 6v + 4$ ……………………………………………………………………………… 1

(V) represents the number of vertices, ($ATD_{less\ p}$) the least penetrating paths, and the paths with the highest penetration ($ATD_{highest\ p}$) are calculated by equation (2).

$ATD_{highest\ p} = (v - 1)^3 / 3 + (v - 1)^2 + 2(v - 1) / 3$ ………………………………………………… 2

The permeability (p) is calculated for the depth of the lowest building at the partial level between its spaces ($ATD_{less\ d}$) through equation (3) and the permeability (p) for the total depth of the building ($ATD_{highest\ d}$) through equation (4), the depth has a relationship with the permeability[29].

$P = ATD_{less\ d} - ATD_{less\ p} / ATD_{less\ p} - ATD_{highest\ p}$ ………………………………………………… 3

$P = ATD_{highest\ d} - ATD_{less\ p} / ATD_{less\ p} - ATD_{highest\ p}$ ………………………………………………… 4

The permeability range is between (0-1), as the high of this ratio indicates the presence of discontinuities and lack of continuity, but when it decreases, this indicates continuity, which achieves adaptation [30].

• Measure the flexibility of the structural system &, functional (Extensibility index)

Extensibility is an expression of the ability to adapt a building and its installation in a simple way to the additional requirements of the user. A work that allows changes, following the principle of separating elements into units that allow for continuous development within the system [31]:

Qualitative z

Quantitative scalability can be measured based on the cost related with adding a new function to the system as shown in the equation [31].

Extensibility = CD_{NF} / (CI_{NF} + CD_{NF})

CD_{NF}: cost of developing a new feature, CI_{NE}: cost of integrating a new feature with other systems

Extension range: $0 < \text{Extensibility} \leq 1$

• Measuring the flexibility of the aesthetic system (self-similarity index)

The passive-similarity expresses the relationship between the factor of scaling and the number of passive-similar parts, that is, the relationship between the original shape and the repeated shape. This indicator constitutes a large part of the flexibility at the micro level. The scientist Hausdorff developed the following equation, to measure the "complexity" of a passive-identical shape [32].

$N=1/r^d$

N = the number of parts similar to the original shape, d = self-similarity, r = the ratio of the scale of the repeated shape to the original shape

To calculate d we take log on both sides $Log(N) = d * log(1/r) \Rightarrow d = Log(N) / log(1/r)$

4.2 Considerations for the selection of architectural projects samples

Three samples of modern designed international buildings were selected with a local sample, and a set of criteria was relied on in the selection of these samples:

• Date of construction: samples of modern constructed buildings with smart technologies in their design, between (2015-2022).

• Functional diversity in the building: with the aim of clarifying the possibilities of smart, intelligent architecture according to several functions.

• Environmental and Climate Diversity: To know the effectiveness and success of smart adaptive architecture in different global environments.

• Importance: All the selected buildings are monuments (Monument) built to achieve the public function required of them.

• Systems used: Adopting (passive- and active design strategies) in various proportions in the design of the building and in the (functional, structural, and beauty) systems.

First, the selected samples will be described (three international samples and one local sample), and then the extent to which they achieve the indicators will be measured.

4.3 Case studies

Table 3: Description of the selected study samples

Sample Code	Sample Information			Sample Description
A	International	**Project Name**	Louvre Abu Dhabi	• New Museum of Classical Art in the Emirates. • The design idea is based on the formation of a group of buildings with flat and harmonious proportions with a translucent roof that allows the entry of diffused light. • Gigantic dome structure performs environmental, aesthetic, structural and functional functions [33].
		Location	Abu Dhabi	
		Designer Name	Jean Nouvel	
		Year	2017	
B		**Project Name**	Amorepacific Headquarters	• The headquarters building of a multifunctional architecture company in Seoul with various areas, as the building works to combine two urban areas to achieve greater social and cultural importance in its context. • The building is designed as a massive courtyard cube that gradually grows in height and carefully manipulates the proportions of the building around a central courtyard with three large panoramic openings connecting this central void to the outer perimeter [34].
		Location	South Korea	
		Designer Name	David Chipperfield	
		Year	2017	
C		**Project Name**	The Edge	• The building is located in the middle of a business district in Amsterdam and has been described as the smartest building in the world.

		Location	Amsterdam	• Designed by building information modeling (BIM) approach. • The building consists of a courtyard that is the social core of the building, and large spaces that are flexible and allow to work anywhere in the building depending on the required level of social communication. • The aesthetic system (building envelope) is characterized by transparency, communication with the surroundings, and the combination of traditional and contemporary design principles, focusing on orientation with to the path of the sun [35].
		Designer Name	Plp Architectural Company	
		Year	2015	
D	**Local**	**Project Name**	Central Bank Of Iraq	• The Central Bank of Iraq (CBI) located in Baghdad, Jadriya, is now under construction, consisting of a platform and a tower, • The functional system of the building consists of banking and social functions. • Smart materials are used in the structural and aesthetic system of the building, including smart glass and pollution-resistant cement, with Glass Fiber Reinforced Concrete (GRC) panels in the tower and the use of Ultra-High Performance Concrete (UHPC) in the entire building structure due to the building's need to support security defenses, • Intelligent Systems Technologies Used in Building Management (BMS) [36].
		Location	Iraq	
		Designer Name	Zaha Hadid	
		Year	2018	

4.4 Measuring the Flexibility Indicators of Intelligent Systems

- **Diversity Index**

The measure of the functional diversity index depends on the functional system of the building represented by the diversity and relative frequency of the functions of building at all levels of the building, and depended on the Shannon diversity index, As shown in the table (4).

Table 4: Shannon Diversity Index Measurement for Samples.

	Sample (A)				
	Functions and Activities	**Function ratio**	**pi**	**log (pi)**	**H' = - Σ [(pi) × log (pi)]**
Functional diversity in macro level	**Public activities** (restaurant, cafeteria, temporary exhibitions)	3/7	0.42	-0.37	0.15
	Semi-public activities (traditional exhibition halls, modern exhibition halls)	2/7	0.28	-0.55	0.15
	Museums	4/7	0.57	-0.24	0.13
	Special Activities (VIP Hall and Administration)	2/7	0.28	-0.55	0.15
	Shannon Diversity Index				H' = 0.58
	Diversity = Richness + Evenness				D = S-1/ ln N + H' /ln S D = 3-1/ln 7 + 0.58/ln3 D = 1.02+0.52 = 1.54
	Sample (B)				
	Cultural activities (museums)	2/7	0.28	-0.55	0.15
	General social activities (entertainment places, sales places, reception hall,	5/7	0.71	-0.14	0.09

	restaurants, cafe)				
	Semi-public social activities (child care, sports venues)	2/7	0.28	-0.55	0.15
	special professional activities(conference center, lecture hall and exhibition)	3/7	0.42	-0.37	0.15
	Semi-private professional activities / offices + library (open floor)	5/7	0.71	-0.14	0.09
	Offices + office (divided with movable partitions)	7/7	1	0	0
	Shannon Diversity Index				H’ = 0.63
	Diversity = Richness + Evenness				D = S-1/ ln N + H’ /ln S D = 3-1/ln 7 + 0.63 /ln3 D = 1.02+0.57 = 1.59
	Sample (C)				
	Public activities (restaurant, cafe and reception)	2/4	0.5	-0.30	0.15
	Semi-public activities (sales stores, exhibition space)	2/4	0.5	-0.30	0.15
	private activities (meeting center, closed offices)	2/4	0.5	-0.30	0.15
	Semi-private activities (open offices)	1/4	0.25	-0.60	0.15
	Shannon Diversity Index				H’ = 0.60
	Diversity = Richness + Evenness				D = S-1/ ln N + H’ /ln S D = 2-1/ln 4 + 0.60/ln2 D = 0.72+0.86 = 1.58
	Sample (D)				
	Public activities (multi-purpose hall, museum, theater)	3/8	0.37	-0.43	0.15
	private activities for administrators (cafeteria and restaurant for employees and another for personalities)	2/8	0.25	-0.60	0.15
	Administrative activities (administrative offices, offices of senior officials and VIPs, meeting rooms)	3/8	0.37	-0.43	0.15
	private activities (financial safe spaces, space for technical spaces)	2/8	0.25	-0.60	0.15
	Shannon Diversity Index				H’ = 0.60
	Diversity = Richness + Evenness				D = S-1/ ln N + H’ /ln S D = 3-1/ln 8 + 0.60 /ln3 D = 0. 96+0.54= 1.5

The diversity of the Macro level as represented by the aesthetic system (building envelope) is measured depended on the Simpson Diversity Index, which takes into account the diversity of adaptive elements in the facades, as shown in Table (5).

Table 5: Simpson diversity index measurement for samples.

	Adaptive elements	Usage rate	$D = 1 - [\Sigma(n/N)^2]$
	Sample (A)		
Diversity in micro level	Fiber concrete slabs	Most used element	$D = 1 - [\Sigma(2/3)^2]$ D=1-0.44 D=0.56
	Layers of steel and aluminum		
	Reflective glass panels	least used element	
	Sample (B)		
	Triple glass	Similar use	$D = 1 - [\Sigma(2/2)^2]$ D=1-1 D=0
	Aluminum panels are heat separated		
	Sample (C)		
	Triple glass	Most used element	$D = 1 - [\Sigma(3/4)^2]$ D=1-0.56 D=0.44
	Solar cell panels		
	Aluminum frames		
	Concrete	least used element	
	Sample (D)		
	Glass fiber reinforced concrete (GRC) panels	Similar use	$D = 1 - [\Sigma(3/3)^2]$ D=1-1 D=0
	Steel reinforced concrete panels (UHPC))		
	Double glazing		

The building represents a continuous dynamic process with the aim of integration and the internal and external influences have an impact on the spatial environment and the intelligence of systems, as they are measured by knowing the extent of spatial diversity, the randomness of functional diversity and the quotient of intelligence, as shown in the table (6).

Table 6: Measurement of the integrated diversity of samples.

	$BIQ = Q R_1 / Q R_2$	$ENT = n / N \Sigma pi \times \log pi$	$HS = 1 - \sum (Ai/TA)^2$
	Sample (A)		
Integrated Diversity	BIQ= 0.5 / 0.5 BIQ=1	ENT = 3/ 7 * (0.58) 0.42 * 0.58=0.24	$HS = 1 - \sum (62000/97000)^2$ HS = 1-0.41 HS=0.59
	Sample (B)		
	BIQ= 0.5 / 0.5 BIQ=1	ENT = 3/ 7 * (0.63) 0.42 * 0.63=0.26	$HS = 1 - \sum (176000 / 216000)^2$ HS = 1-0.66 HS = 0.34
	Sample (C)		
	BIQ= 0.5 / 0.7 BIQ=0.7	ENT = 2/ 4 * (0.60) 0.5 * 0.60=0.3	$HS = 1 - \sum (30057/ 40000)^2$ HS = 1-0.56 HS = 0.44
	Sample (D)		
	BIQ= 0.5 / 0.5 BIQ=1	ENT = 3/ 8 * (0.60) 0.37 * 0.60=0.22	$HS = 1 - \sum (16000 / 20000)^2$ HS = 1-0.64 HS = 0.36

- **Change Index**

The change is represented as a response and appears when there is a difference between user expectations and building performance (user suitability) or a difference between technical specifications and building performance (technical suitability), both of which are affected by external factors and technological development, as the indicator was measured qualitatively as in the table (7).

Table 7: Measurement of change index of samples.

Impulse	Response method	Scale of adaptation	Adaptive element
Sample (A)			
The building did not achieve the change indicator			
Sample (B)			
• Technological changes • Climatic changes • Functional reasons	The use of high-efficiency technologies, including (automatic interior blinds to control direct sunlight or reflections from neighboring buildings, shading system (brise-soleil\, DALI sensors) aimed at reducing energy consumption and providing optimal comfort for the user.	• Macro level • Micro level.	• Mechanical • Pneumatic • Hydraulic • Material
Sample (C)			
• Technological changes • Climatic changes • Functional reasons	The use of shading system, solar panels, and low-emission LED lighting system with daylight sensors to reduce energy consumption, Hot Desking system to save spaces and reduce structural elements.	• Macro level • Micro level.	• Mechanical • Pneumatic • Hydraulic • Material
Sample (D)			
• Technological changes • Climatic changes • Functional reasons	The building relied on sustainable smart materials with the integration of all technologies and an intelligent management system in the building, and all parts were designed digitally.	• Macro level • Micro level.	• Mechanical • Pneumatic • Hydraulic • Material

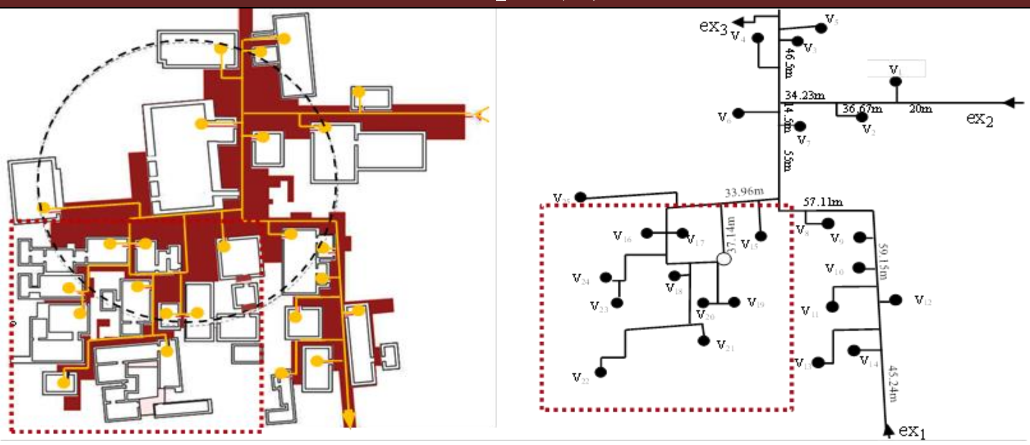
- **Permeability Index**

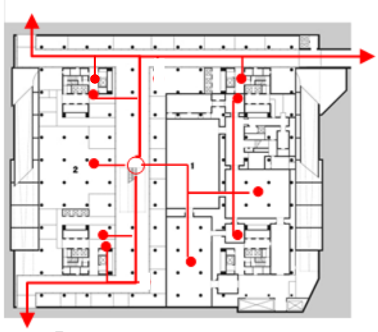
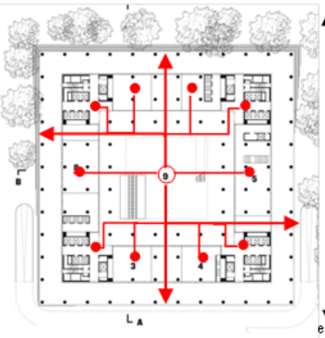
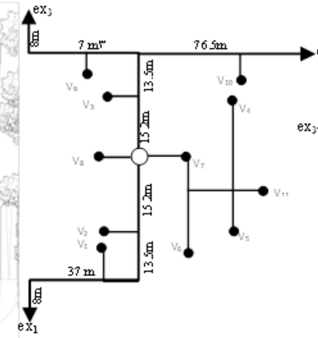
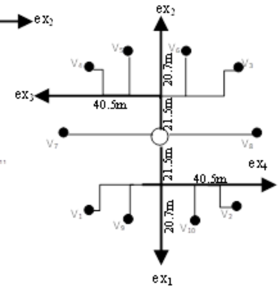
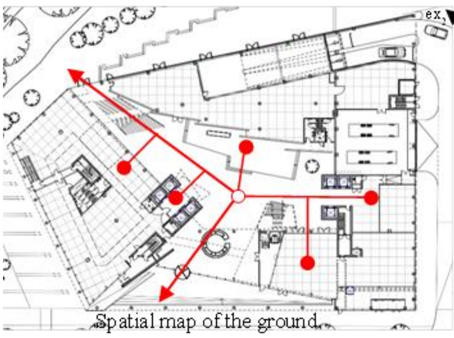
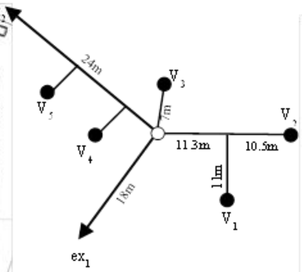
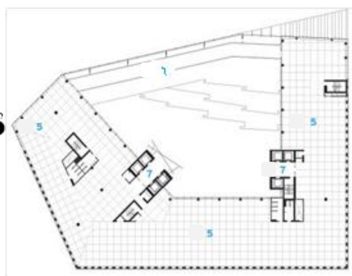
The permeability will be measured at the micro levels using the qualitative method, and the macro level using the quantitative method, as shown in Table (8).

Table 8: Measurement of permeability index of samples.

Permeability = Accessibility + Visibility					
Sample (A)					
	Images	**Elements**	**Accessibility**	**Visibility**	**Permeability**
Permeability in micro		Concrete slab wall with limited openings	High (natural force)	Moderate (out -in)	High + Moderate= Moderate
		Concrete walls	High (human flow)	High (in-in)	High+ High = High
		Roof with openings (dome)	High (natural force)	High (out -in)	High+ High =High
	Sample (B)				

		Building envelope in reflective glass with openings	High (natural force)	High (out- in)	High + High= High
	Sample (C)				
		Triple glass combination.	High (natural force)	Moderate (out- in)	High + Moderate = Moderate
		open system	High (human flow)	High (in-in)	High + High= High
	Sample (D)				
		Glass wall (double glazing).	High (natural force)	High (in-out)	High + High= High
		Concrete wall with limited openings	High (natural force)	Moderate (out-in)	High + Moderate = Moderate
		Roof with openings	High (natural force)	High (in-out)	High + High= High

Permeability in macro level				
	Sample (A)			
				
	Entrances	Number of path nodes	Depth	Measurement equations
	Second Entrance	25	The Least	$ATD_{less\ p} = 2v^2 - 6v + 4 \rightarrow ATD_{less\ p} = 2(25)^2 - 6(25) + 4$ $ATD_{less\ p} = 1104$ $P_1 = ATD_{less\ d} - ATD_{less\ p} / ATD_{less\ p} - ATD_{highest\ p}$ $P_1 = 231.5 - 1104 / 1104 - 5200 \rightarrow P_1 = 0.21$
	First Entrance		The Higher	$ATD_{highest\ p} = (v-1)^3/3 + (v-1)^2 + 2(v-1)/3$ $ATD_{highest\ p} = (25-1)^3/3 + (25-1)^2 + 2(25-1)/3$ $ATD_{highest\ p} = 5200$ $P_2 = ATD_{highest\ d} - ATD_{less\ p} / ATD_{less\ p} - ATD_{highest\ p}$ $P_2 = 232.6 - 1104 / 1104 - 5200 \rightarrow P_2 = 0.21$
	Third Entrance		The Least	$P_3 = ATD_{less\ d} - ATD_{less\ p} / ATD_{less\ p} - ATD_{highest\ p}$ $P_3 = 87.1 - 1104 / 1104 - 5200 \rightarrow P_3 = 0.22$
	Sample (B)			

 Basement	 Ground floor	 Spatial plan for the basement	 Spatial plan for ground floor
Basement floor			
First Entrance	11	The Least	$ATD_{less\ p} = 2v^2 - 6v + 4$ $ATD_{less\ p} = 2(11)^2 - 6(11) + 4 \rightarrow ATD_{less\ p} = 180$ $P_1 = ATD_{less\ d} - ATD_{less\ p} / ATD_{less\ p} - ATD_{highest\ p}$ $P_1 = 86 - 180 / 180 - 440 \rightarrow P_1 = 0.36$
Second Entrance =Third Entrance		The Higher	$ATD_{highest\ p} = (v-1)^3 / 3 + (v-1)^2 + 2(v-1) / 3$ $ATD_{highest\ p} = (11-1)^3 / 3 + (11-1)^2 + 2(11-1) / 3 \rightarrow$ $ATD_{highest\ p} = 440$ $P_2 = ATD_{highest\ d} - ATD_{less\ p} / ATD_{less\ p} - ATD_{highest\ p}$ $P_2 = 105.2 - 180 / 180 - 440$ $P_2 = 0.29$
Ground floor			
First Entrance = Second Entrance	10	The Least	$ATD_{less\ p} = 2v^2 - 6v + 4 \rightarrow ATD_{less\ p} = 2(10)^2 - 6(10) + 4 \rightarrow$ $ATD_{less\ p} = 144$ $P_1 = ATD_{less\ d} - ATD_{less\ p} / ATD_{less\ p} - ATD_{highest\ p}$ $P_1 = 42.2 - 144 / 144 - 330 \rightarrow P_1 = 0.55$
Third Entrance= Fourth entrance		The Higher	$ATD_{highest\ p} = (v-1)^3 / 3 + (v-1)^2 + 2(v-1) / 3$ $ATD_{highest\ p} = (10-1)^3 / 3 + (10-1)^2 + 2(10-1) / 3 \rightarrow$ $ATD_{highest\ p} = 330$ $P_2 = ATD_{highest\ d} - ATD_{less\ p} / ATD_{less\ p} - ATD_{highest\ p}$ $P_2 = 62 - 144 / 144 - 330$ $P_2 = 0.44$
Sample (C)			
 Spatial map of the ground	 Floor ground floor	 Typical floor	
First Entrance	The Least	5	$ATD_{less\ p} = 2v^2 - 6v + 4 \rightarrow ATD_{less\ p} = 2(5)^2 - 6(5) + 4 \rightarrow$ $ATD_{less\ p} = 24$ $P_1 = ATD_{less\ d} - ATD_{less\ p} / ATD_{less\ p} - ATD_{highest\ p}$ $P_1 = 18 - 24 / 24 - 40 \rightarrow P_1 = 0.38$
Second Entrance	The Higher		$ATD_{highest\ p} = (v-1)^3 / 3 + (v-1)^2 + 2(v-1) / 3$ $ATD_{highest\ p} = (5-1)^3 / 3 + (5-1)^2 + 2(5-1) / 3$ $ATD_{highest\ p} = 21.33 + 16 + 2.66 \rightarrow ATD_{highest\ p} = 40$ $P_2 = ATD_{highest\ d} - ATD_{less\ p} / ATD_{less\ p} - ATD_{highest\ p}$

				$P_2 = 24 - 24/24 - 40 \longrightarrow P = 0$
	Sample (D)			
	The indicator cannot be measured due to unavailability of building floor maps			

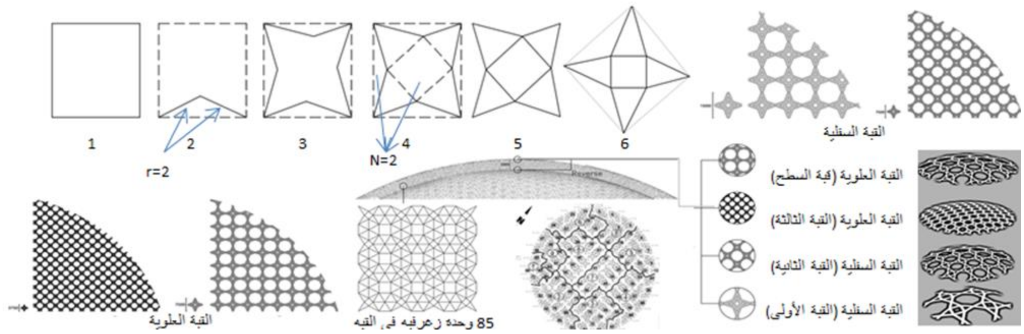
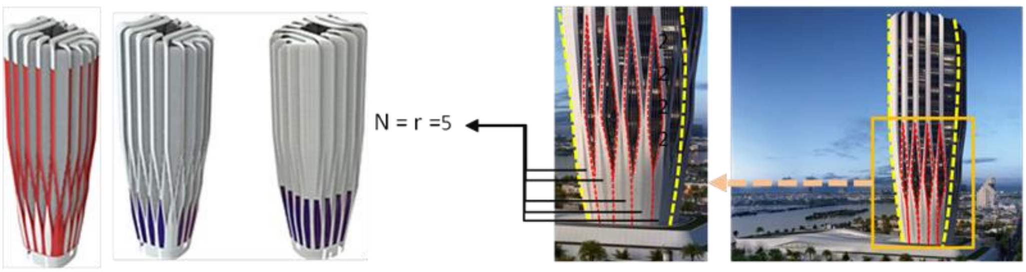
- **Extensibility Index**

The samples did not achieve the index of extension because all the selected samples were modern designed and were not subjected to adjustment and renovation mechanisms.

- **Self-Similarity**

The self-similarity index is measured at the micro level of the building, especially in the aesthetic system, as shown in the table (9).

Table 9: Measurement of Self-Similarity index of samples.

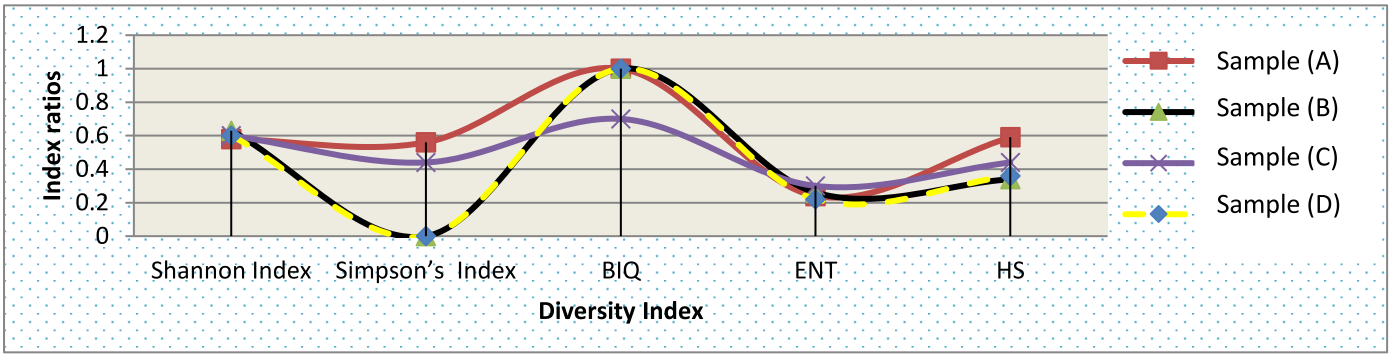
<table>
<tr><th>Measurement equation
d= log (N)/ log (1/ r)</th><th>Details of self-similarity in samples</th></tr>
<tr><td colspan="2">Sample (A)</td></tr>
<tr><td>$d = log(2) / log(1/2)$
d=1</td><td>
</td></tr>
<tr><td colspan="2">Sample (B)</td></tr>
<tr><td>$d = log(8) / (1/3)$
d=1.8</td><td>
</td></tr>
<tr><td colspan="2">Sample (C)</td></tr>
<tr><td colspan="2">The building did not achieve the self-similarity indicator</td></tr>
<tr><td colspan="2">Sample (D)</td></tr>
<tr><td>$d = log(5) / log(1/5)$
d=1</td><td>
</td></tr>
</table>

5. Results and Discussion

The results of the descriptive and quantitative measurement of samples showed that flexibility of the measures taken in the building came in all samples towards integration of two systems, while when measuring diversity index according to the Shannon index, similar results appeared between samples and all of them are within category (Neutral Diversity), as this means that samples consist of functional gender one is supported by other functions.

While the results of the Simpson index revealed the distinctiveness of its sample (B) with a value of (0), which is an indication of dependence on a basic adaptive element in the building envelope, while two samples (A, C) achieved a diversity of (0.44-0.56), While local sample (D) consists of adaptive elements that are cohesive and integrated with each other, as it achieved a diversity of (0) at the micro level as it is in sample (B).

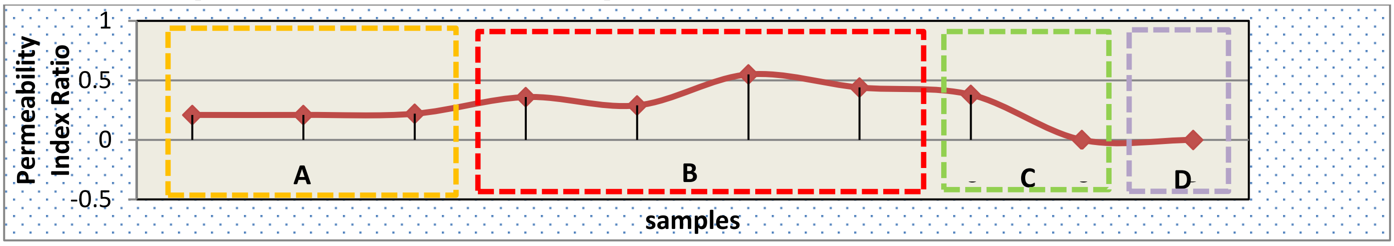
The results of integrated diversity of samples showed the integration of diversity in two samples (A, B) and also in the local sample (D) through the integration of active and passive strategies with a value of (1) and randomness with a value ranging from (0.22-0.26) and with spatial diversity ranging between (0.34-0.59) While sample (c) did not achieve integrated diversity because of its dependence on the active strategy more than passive strategy, as shown in the chart (1)



Graph 1 Simulation of the ratio diversity index of samples with the local sample.

The two samples (A and B) achieved an indicator of change at the macro level of the building by relying on the smart techniques used, while change indicator did not achieve sample (C) because it relied on passive strategic mechanisms in response to changes, while the descriptive results of the change indicator showed in the local sample (D), Similar to what is shown in (B) as it keeps with continuous changes using smart technologies.

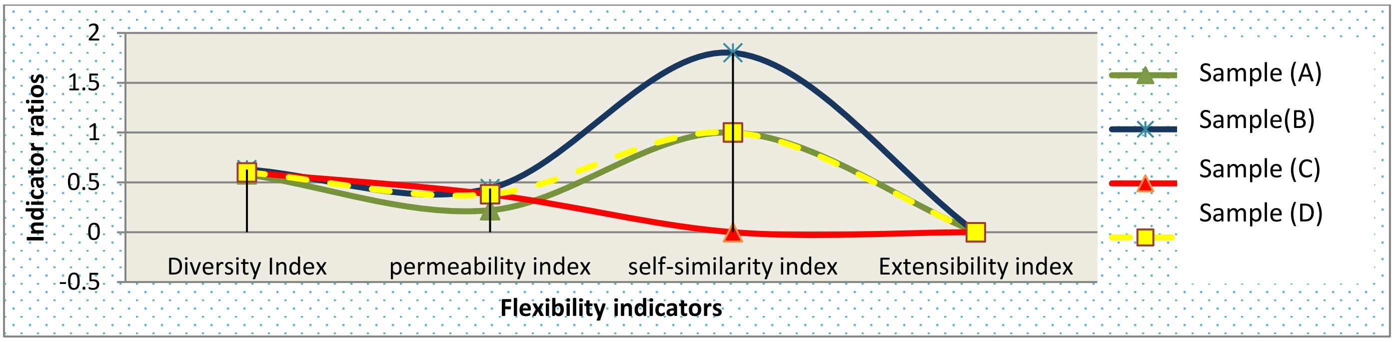
The results of measuring the permeability index revealed that sample (B) differed from the other samples because it achieved an average permeability (0.44-0.55) due to its dependence on entrances on two floors, different the other samples, which achieved high permeability close to (0) and ranging between (0 - 0.38) the results of local sample (D) showed proximity to the results of the samples, especially closer to the sample (B), as shown in the chart (2).



Graph 2 Permeability Ratios of Samples

While the self-similarity index appeared in its sample (A) at both the macro and micro levels and achieved a percentage of (1), while it achieved a high percentage (1.8) in its sample (B) because the building block was formed on the basis of the self-similarity of one shape, while the indicator was not achieved in its sample (C) Because the building block did not consist of repeating shapes of original building block shape, while local sample self-similarity result (D) revealed a value similar to the self-similarity value in its sample (A) because the external structure frames an alternating pattern of similar, open and closed elements that visually simulation light reflected from the river, enhancing the dynamism of the design.

The samples showed integration of indicators, unless for the extension, which was not achieved in samples because they are modern designed and were not exposed to mechanisms of adjustment and renovation. Nevertheless, the sample (B) and local sample (D) achieved the highest possibility of spatial adaptation and integration with the surroundings, as shown in chart (3) Indicators that have been quantified.



Graph (3) Flexibility indices ratios for the selected samples.

6. Conclusions

1. The building's intelligence is represented in the flexibility resulting from integration of passive and active strategies at both levels (macro and micro) and method of designing and employing systems (functional, structural, and aesthetic) with use of different techniques and technological methods so that the building's ability to adapt to cultural and environmental contexts and technological developments as needed Intelligence in design and support using smart technologies in a balanced method and according to the influence and the nature of systems integration, or at least integration of two systems.
2. Buildings designed to be adaptive based on intelligent systems have the ability to make future changes easily and with lower expenses to convention the evolving needs of their occupants.
3. The diversity of functional system is limited to one dominant functional gender in the micro level of the building and other supporting functions as in samples that have been studied, while the diversity at micro level is limited to the diversity of sizes, spaces, heights, and elements of building envelope adaptation and is linked with the structural and aesthetic system.
4. Depended on the passive strategy in special to achieve systems intelligence, in addition to integrating smart technologies with design to achieve the quality of the internal environment and the coherence of the levels of the spatial scope, as in the local sample.
5. The ideas of architecture with flexible, intelligent systems can be applied to a variety of environments and to types of multifunctional buildings ranging from entertainment, residential, work and public environments, they can be convened in offices as in sample (B), museums as in sample (A), and administrative buildings as in the local sample and other.

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