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EXPLORING THE ABILITY OF STRUCTURAL SYSTEMS TO ACHIEVE FLEXIBILITY IN ARCHITECTURE

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ABSTRACT

Architecture is distinguished from any other field in that it is an artistic, technical and functional science that is concerned with aesthetics, functionality and the environment. Due to architecture being closely linked to structural systems, structural systems are the first contributor to enhancing the exploitation of building functions. The behavior of the structural systems in the building is according to many determinates, the most important of which is how flexibility can be achieved in the building. Furthermore, flexibility is a crucial aspect of architecture because it allows buildings to adapt and respond to changing needs. In the case of structural systems, flexibility refers to their ability to accommodate modifications, reconfigurations, or expansions without compromising the integrity or functionality of buildings such as the use of modularity, adaptive elements and open-plan designs where architects develop their designs that can evolve alongside Combined with user needs, providing longevity, versatility and sustainable use of resources. The research aims to explore the significance of the flexibility of structural systems and its effect on adapting buildings to achieve innovative architecture aesthetically, functionally and environmentally. The research follows the theoretical study approach, where the research discusses the concept of flexibility and its types that vary according to the structural system. The analytical study evaluates examples of buildings that achieve flexibility through structural systems. Finally, the research concludes the important results related to opportunities for achieving flexibility in buildings in order to utilize the potential of structural systems to achieve adaptive architecture.

KEYWORDS: Structural systems, Flexibility, Architecture.

إستكشاف قدرة الأنظمة الإنشائية على تحقيق المرونة في العمارة

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الملخص

تتميز الهندسة المعمارية عن أي مجال آخر بأنها علم فني وتقني ووظيفي يهتم بالجماليات والوظيفة والبيئة. ونظرًا لإرتباط العمارة ارتباطًا وثيقًا بالأنظمة الإنشائية لكونها هي المساهم الأول في تعزيز إستغلال وظائف المبنى. كما أن تقييم سلوك الأنظمة الإنشائية في المبنى يكون وفق عدة محددات أهمها كيفية تحقيق المرونة في المبنى. علاوة على ذلك، تعد المرونة جانبًا حاسمًا في العمارة لأنها تسمح للمباني بالتكيف والإستجابة للإحتياجات المتغيرة. وفي حالة الأنظمة الهيكلية تشير المرونة إلى قدرتها على استيعاب التعديلات أو إعادة التشكيل أو التوسعات دون المساس بسلامة المبنى أو وظائفه مثل استخدام الوحدات النمطية والعناصر التكيفية والتصميمات ذات المخطط المفتوح، حيث يقوم المهندسون المعماريون بتطوير تصميماتهم التي يمكن أن تتطور جنبًا إلى جنب مع إحتياجات المستخدم مما يوفر طول العمر والتنوع والإستخدام المستدام للموارد. يهدف البحث إلى إستكشاف أهمية مرونة الأنظمة الإنشائية وأثرها في تكييف المباني لتحقيق عمارة مبتكرة جماليا ووظيفيا وبيئيا. كما يتبع البحث

منهج الدراسة النظرية حيث تناول البحث مفهوم المرونة وأنواعها التي تختلف باختلاف النظام الهيكلي. وتقوم الدراسة التحليلية بتقييم أمثلة المباني التي تحقق المرونة من خلال مرونة الأنظمة الإنشائية لها. وأخيراً توصل البحث إلى نتائج مهمة تتعلق بفرص تحقيق المرونة في المباني من أجل الإستفادة من إمكانات الأنظمة الإنشائية لتحقيق العمارة التكيفية.

الكلمات المفتاحية : الأنظمة الإنشائية، المرونة، الهندسة المعمارية.

1. INTRODUCTION

In recent decades, the economic, environmental and social changes and requirements have increased rapidly in our lives which is directly reflected in architecture. On the other hand, many buildings designed in the name of resilience are in fact completely inflexible. For example, some buildings have spaces that are not integrated with their structural systems or are not suitable for use without regard to other considerations such as functional, environmental, or aesthetic. Therefore flexibility has become one of the most important trends that meet the needs that face architecture design variables, whether functional, environmental, or aesthetic. One of the most important factors that help to achieve flexibility in architecture is structure systems. This research aims to study the effect of structure system location on achieving flexibility in the building.

2. The Concept of flexibility

The term of flexibility is used in multiple fields such as biology, economics, and architecture .etc. It can be defined as “the ability of a system to respond to potential internal and external requirements in an appropriate and effective method” [1].

2.1. Flexibility in architecture

Flexibility in architecture is necessary because of the continuous changes in our lives as well as human's inner desire for diversity and innovation in their living requirements. This paper discusses some of the numerous attempts that were made to define flexibility concepts throughout a specific framework.

- **Flexibility** in architecture enables modifications without causing obstacles or damage in building construction, which indicates the need to take these modifications into consideration in the early design stages [2].
- The main objective of **flexibility** in architecture is to provide variation among the units in a spatial arrangement; furthermore, flexibility encompasses the capacity of units to be flexible and adapt over time, as well as the ability of buildings to accommodate new uses" [3] .
- **Flexibility** refers to the ability of a structure to adapt to changing needs and maximize its value throughout life [4].
- In ecological design, **Flexibility** refers to the capacity to modify and restructure the built environment to adapt to evolving environmental needs [5].
- **Flexibility** refers to the ability of structures to adapt to the evolving needs and expectations of societies, including cultural, technological, and economic changes [6].
- Three concepts of **flexibility** are present: spatial, functional, and aesthetical. These relate to the ability to change space, function, and identity throughout time, respectively. Therefore, flexibility increases building life and reduces waste, enabling buildings to meet sustainability standards for a longer time [7].
- External **flexibility** is Adding a full block to a building with the goal of expanding it to satisfy needs or add a new function. It also refers to situations in which exterior

modifications are performed for building development purposes, taking into account new practical, social, and aesthetic requirements, without compromising interior design [8].

Through the previously mentioned attempts that tried to define the concept of flexibility, some properties of flexibility can deduced, such as:

- Components can be added or removed without compromising structural integrity.
- The elements' ability for changing them out for movable partitions.
- The diversity of the units is in the architectural arrangement.
- Appreciate the units to adapt and change over time.
- The building adapted to the new functions.
- The effectiveness of flexibility meets the developed demands.
- Maximizing the value of the building throughout its life cycle.
- Changing and reorganizing the built environment to meet environmental requirements.

3. Principles of flexibility in architecture

There are four key factors that identify the flexibility in the building includes (adaptability, mobility, transformability and interaction) [9] .See **Fig. 1.**

Principles of flexibility			
Adaptive buildings are buildings that accommodate different functions determined by the activities of the occupants and the building can be adapted to one or multiple purposes.	'Mobility' refers to buildings that can physically change their position from one place to another. Hence achieve the flexibility and variation of their purpose and reuse.	Transformable buildings are capable of changing their area, shape, and appearance through physically expressing their internal surfaces, external shell, or structural elements.	Interactive of Flexible buildings will be achieved when the all of elements of building enhances the interaction between spaces and occupants between each other.

Fig. 1. Principles of flexibility (Elmokadem, A., etal, (2019)

4. Structure systems and flexibility

The structural systems represent the most important elements of the building that achieve flexibility in the building. Whenever the structure systems have more flexibility, the building will meet the desires of its occupants. Therefore, flexibility principles can be applied to the structural system as an integral part of the building. Furthermore, the structure's characteristics and relations are very influential in the decision process of architectural design. See **Fig. 2.**

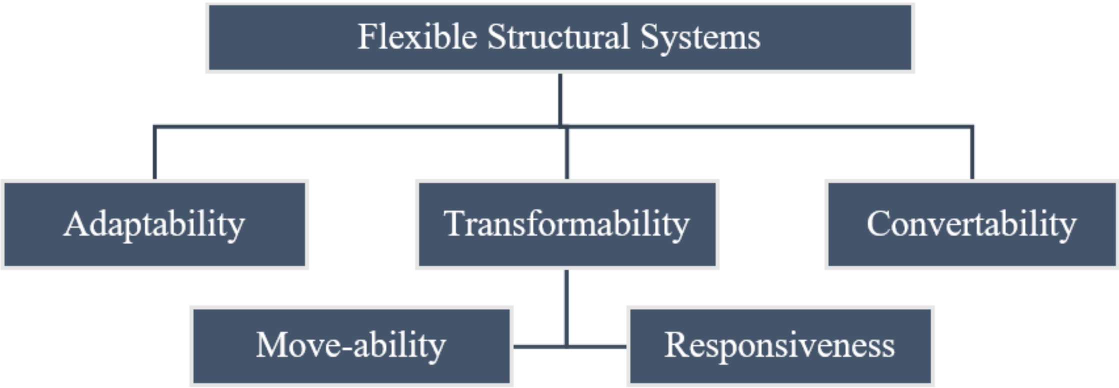


Fig. 2. Flexible structure systems factors

4.1. Structural adaptability

The capability of a structural system to accommodate numerous functions without changing the building itself such as changing the spatial spaces, adding or removing walls, reinforcing the structure, or making other adjustments to enhance the building's functionality, safety, or aesthetic appeal that adapting the structure according to user needs. “Open plan” is one of the most important examples for adapting the structure [10]. See **Fig. 3.**

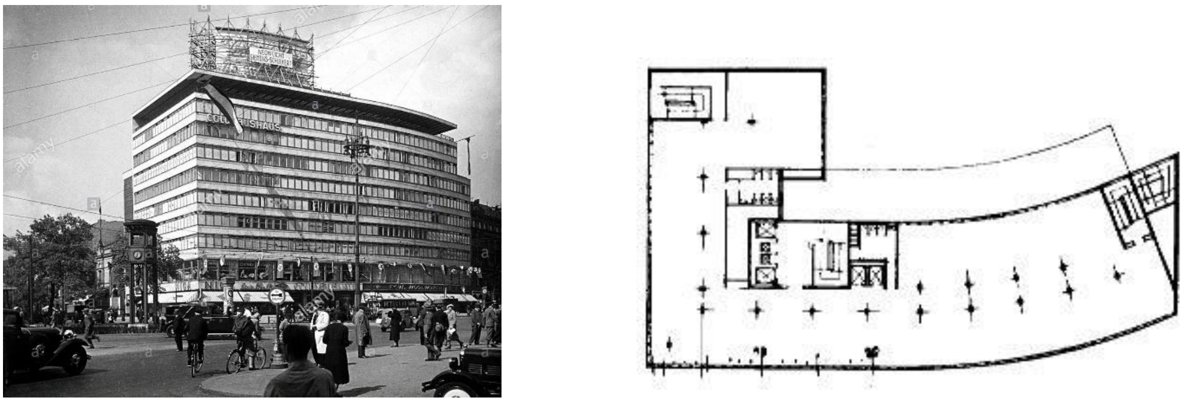


Fig. 3. Columbus House, Berlin, 1931 Architect: Erich Mendelson

4.2. Structural transformability

This type of structure system allows for the interior and exterior spaces to be changed in response to meet certain requirements [10].

This type includes two subsets of transformability:

4.2.1. Move-ability: Moveable structures can be repositioned in the environment many times without being changed in any way of structural systems. For example expositions, moveable fabric structures, re-locatable retail units, etc. See **Fig. 4.**

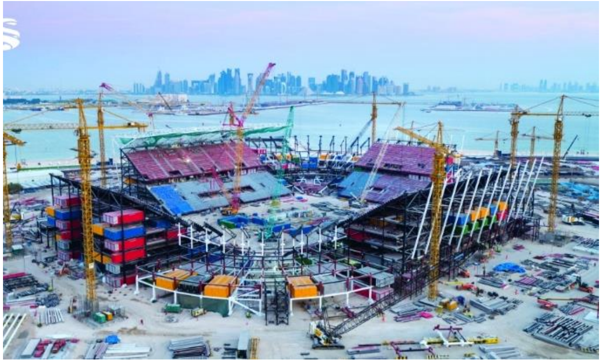


Fig. 4. Qatar's Stadium 974, 2022

4.2.2. Responsiveness: This structure system enables the modification of interior and exterior spaces to meet functional, aesthetic, or environmental requirements, often temporary, such as moveable facades and retractable roofs, based on climatic conditions. See **Fig. 5.**

Fig. 5. Mercedes-Benz Stadium, 2017

4.3. Structural Convertibility

Structural convertibility is the ability to adapt a building's function to its internal requirements, improving interaction between spaces and users without structural obstacles. This involves planning conversion during the design phase to assess future needs and reduce time and cost. The resulting changes are often permanent, allowing sufficient space for future extension, such as allowing extensions in defined zones and undefined zones [10]. See **Fig.6**

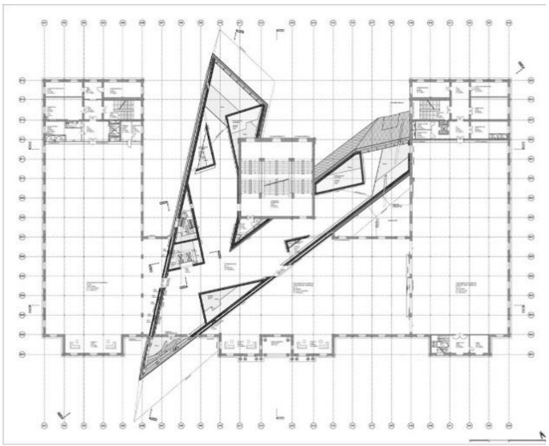


Fig. 6. Dresden's Military History Museum, 2011

5. Achieving of flexibility according the spatial arrangement of structural systems with building envelope

The structure system spatial contributes to achieve flexibility of the building. Therefore, there is a significant relationship between the structural system and the building envelope. The relationship between structural system and building envelope can be classified into three cases:

A) Building envelope enclosed in the Structural system (active): In this case, the structural system is completely outside the building envelope, and this makes the design of the interior spaces free without obstacles for the structural system. See **Fig.7.**

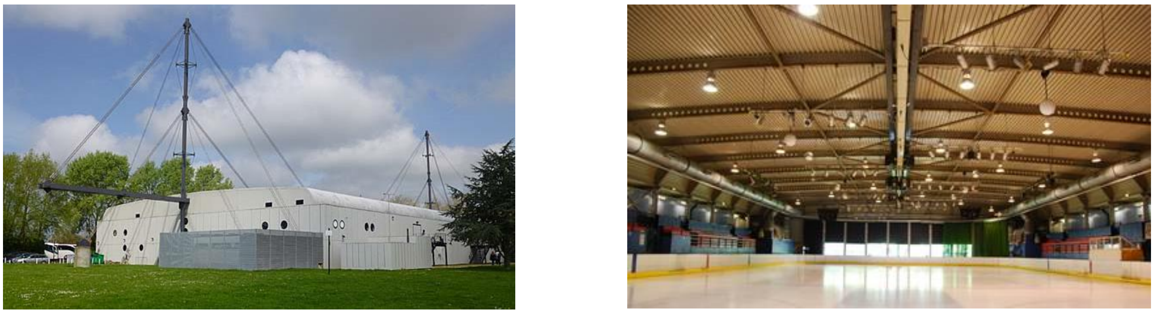


Fig. 7. Oxford Ice Rink, UK, Nicholas Grimshaw & Partners, 1985

B) Structural system enclosed in the building envelope (active/passive): this case has an impact on the interior spaces, as the structural system sometimes reduces the use of spaces or affects the spaces adjacent to the structural elements, and this case has a (passive) effect. See **Fig. 8.** On the other hand, there are (active) effects when the structural system and spaces are combined in an ideal way, it depends on the design skills of both the architect and structural designer. See **Fig. 9.**

Fig. 8. Bridge Academy, London, UK, Building Design Partnership, 2007

Fig. 9. Research Centre, Seibersdorf, Austria, Coop Himmelb(l)au, 1995

C) **Structural system compacted within the building envelope (active):** the shell structures are the most obvious type of building that expresses this case, where the structural system integrates with the building envelope. The structure system supports the building envelope, which in turn increases the opportunities for exploitation of the spaces inside the building. See **Fig.10.**

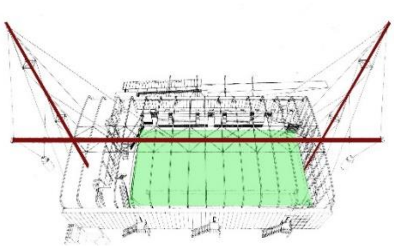
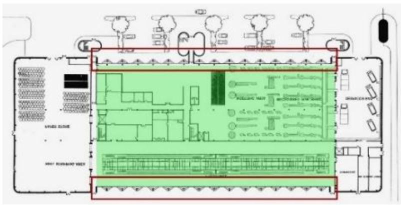
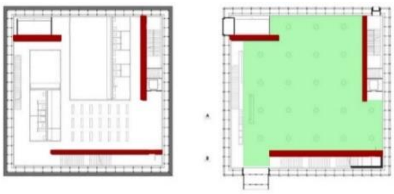
Fig. 10. Centre Pompidou-Metz, Architect: Shigeru Ban, 2010

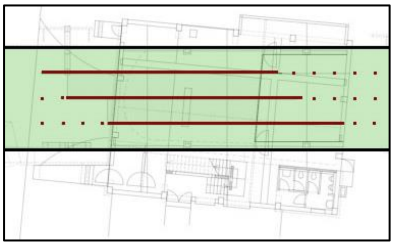
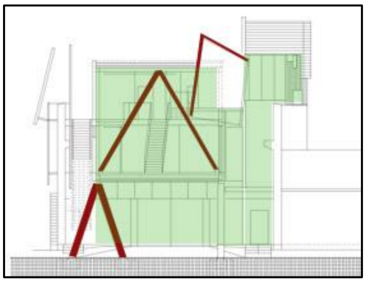
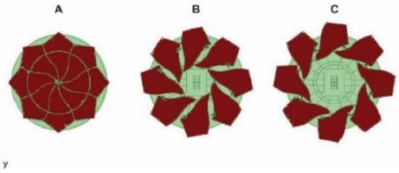
Each of the above cases has different features such as (Form, Function, aesthetics, etc.). Furthermore, they have effectiveness in achieving building flexibility. The following table illustrates the effect of the location of the structure system in the building and its relationship to the building envelope on achieving flexibility as follows **(Table 1):**

- **(Oxford Ice Rink, UK, Nicholas Grimshaw & Partners, 1985):** The building's flexibility was achieved throughout an external structure system consisting of two masts, tension rods, and a central spine beam, allowing for a large rink space without any structural obstacles. See **Fig.11.**
- **(Financial Times printing works, London, Nicholas Grimshaw & Partners, 1988).** The external structure is represented by columns of the north and south facades which are located outside the building envelope provide flexibility and allow for adjustments in internal spaces. See **Fig.12.**
- **(The Art Museum, Bregenz, Austria, Atelier Peter Zumthor, 1997)** has a maximum flexibility in its internal spaces that is achieved by an internal structure consisting of three concrete structure walls (shear walls) which allow for diversity of exhibition spaces in the museum. See **Fig.13.**
- On the other hand, Incorrect verification of the structural system used can lead to disruption of interior spaces of the building as shown in **(Research Centre, Seibersdorf, Austria, Coop Himmelblau, 1995)**, where the flexibility was not achieved in this building in order to the spatial and orientation of columns in the internal spaces. See **Fig.14.**

- Shell buildings have more flexibility of building due to the compact structure system of building envelope as presented in **(Heydar Aliyev Center, Zaha Hadid Architects, 2014)**. In addition, the shell structure system enhances flexibility through the shell roof that covers large spaces that have different highs and multi-story as well as makes the building adapt to a lot of requirements of the building. See **Fig.15**.
- The shape of the structure may change completely to be responsive to diversity and adaptation to the needs of the building, as is the case in the building **(Qizhong Forest Sports City Arena, 2005)**, in which the structural structure and the building envelope work as one element. See **Fig. 16.**

Table 1. Relationship between the spatial arrangement of structural systems and the flexibility in buildings

Selected buildings			Adaptability	Transform-ability		Convertibility	Flexibility overall
				Move-ability	Responsive-ness		
Building envelope enclosed in Structural system			●	⊗	⊗	●	Achieved
	Fig. 11. Oxford Ice Rink, UK, Nicholas Grimshaw & Partners, 1985						
			●	⊗	⊗	●	Achieved
	Fig. 12. Financial Times printing works, London, 1988						
Structural system enclosed in building envelope			●	⊗	⊗	●	Achieved
	Fig. 13. Art Museum, Bregenz, Austria, Atelier Peter Zumthor, 1997						

	 	 Plan  Section	⊗	⊗	⊗	●	Not achieved
	Fig. 14. Research Centre, Seibersdorf, Austria, Coop Himmelb (l)au, 1995						
Structure system compacted within building envelope			●	⊗	⊗	●	Achieved
	Fig. 15. Heydar Aliyev Center, Zaha Hadid Architects, 2014						
		 A B C	●	⊗	●	●	Highly achieved
	Fig. 16. Qizhong Forest Sports City Arena, 2005						

Conclusions

The research paper discussed the opportunities to achieve flexibility in buildings through the relationship between the spatial arrangement of structural systems and the building envelope. Hence, the research concluded the following:

- The opportunities of achieving flexibility increase in two cases (the building envelope enclosed in the structural system - the structural system enclosed in the building envelope), where there are no obstacles limiting the structure's adaptation to internal spaces.
- In the case of a structure system compacted within a building envelope), achieving flexibility depends on the compatibility and spatial arrangement of the structural elements with the interior spaces to prevent any conflicts between the structural system and functional disturbances.
- Flexibility in buildings contributes to the adaptation of buildings to requirements (aesthetic, functional and environmental), which achieves sustainable architecture.

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