Effect of Structural Design Efficiency in Achieving Stability and Efficiency of the Architectural Design

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Abstract. The research dealt with the historical development of construction systems, their compatibility with architectural spaces, and the functional and expressive aspects of the various construction systems. Then, it discussed the creativity in the construction systems, which composed of structural elements, and elements interrelated and interactive with each other, in order to complete the structural function specified for design, with the provision of stability elements. The research was conducted based on the analytical method by adopting a field study and a research tool, which was the questionnaire form used in collecting data from the study sample to discover the effect of the contemporary construction systems and materials on the architectural spaces, after verifying its validity and performing the statistical analysis. The research sample was selected according to the study variables (gender, education, and years of experience). It was found that the diversity in construction materials and systems can lead to flexibility in the architectural space. Also, a comfortable space, problem-free, can be a result of the compatibility between architectural design and structural design. Furthermore, there is a functional impact of modern construction materials on space by adopting the surface texture of the construction materials to address the architectural space design.

1. Introduction
The contemporary construction materials contributed to adapting human life and environmental conditions to his desire in developing life permanently and regularly to create an attractive and comfortable atmosphere. Architects contributed to the adaptation of construction materials to form models and designs in a very creative and accurate manner, which expressed the development in the construction materials used for general and interior architectural designs. The development of materials and their compatibility with designs and the architectural concept ideas, as well as the impact of technological development on these materials, has a functional and aesthetic impact on the architectural spaces and their symbolic and expressive role.

2. Literature review
The researches and previous studies, especially those talked about the contemporary construction materials and their impact on the performance of the architectural space, have been reviewed.
1. The structural requirements of single curve suspended structures and their effects on Architectural form and function [1].

The aim of this research was to identify the structural requirements of the suspended structural blocks (single curve), especially the requirements of affording the horizontal component of the reaction, and how the architect deals with them to make them architecturally functional to be fully utilized architecturally and constructively. This was done by defining the suspended structures, their types and
their development, as well as the study of the structural blocks (single curvature), their requirements and their effect on the solution and the architectural shape [1].

2. The modern materials in interior finishing [2].

The diversity of construction and interior finishing materials has become interesting. These materials have various and high specifications of development and customization, as well as a diversity in specifications and price. The researcher can observe the random use of these materials by many unqualified workers, and thus negatively affects the appearance of work, its quality and its cost [2].

3. The Structural systems and expressional function for Airport Terminals’ buildings [3].

The research concentrated particularly on studying the contemporary passenger buildings, which were complex functional structures, in which flexibility and technology play an important role, as well as the human values that must be provided in these structures, such as the physical and psychological comfort of passengers. In these structures, the architectural shape plays a distinctive role in contrasting the feature of the architecture and its identity. The research focused on the role played by airport buildings recently, and the need to studying their expressive and aesthetic levels and methods of applying them, in addition to studying how extent they are integrated with structural level. This integration plays an expressive role in giving a symbolic and iconic expression to it [3].

Through a review of the previous studies, the construction methods used in the event halls or multi-purpose halls as well as the effect of construction materials and architectural elements on the interior space of the halls were not addressed.

3. Historical technical and technological development and its impact on modern construction materials

The interior architectural finishing of the mid-20th century limited to using clay, gravel, stone and wood as primary materials. Despite the limitations of these materials, they were sufficient to give the architectural space essential conditions for a comfortable and secure life.

Since the development of interior design is associated with the development of human thought in all fields, the industrial revolution had an important role in changing the intellectual architectural attitudes represented by the development of construction materials, skills and technical methods, which led to the liberation of the architectural space from the specific and fixed form imposed by the traditional construction materials and systems, which led to the emergence of large internal spaces pierced by thin columns. Therefore, the interior space has become more open and characteristic of the modern movement in design. [2].

4. Architectural space

4.1. Structural elements contributing in the space determination

It is not possible to implement any architectural space without a constructional tool, which puts some restrictions to expand the space, and the degree of restriction varies according to the structural system used in the construction. Contradiction and inconsistency among the constructional targets sometimes can control the arrangement of spaces. Through the research about the concept of space and its development, it was noted that the constructional work has been replaced with real structural elements. Also, the concept of division and rigidity has been transferred to the concept of transparency and lightness. So, the architectural space has determinants that have a significant effect on the way of designing the space, in addition to the sense of space. However, the change of these parameters, with minimal changes, can result in an architectural form [4].

4.2. Requirements of inner architectural space design

They are classified as below; [4]

1. Functional requirements
   a. Safety and security of motional performance.
   b. Achievement of the main function by adaption between part and whole.
   c. Efficiency of raw materials for functional performance.
   d. Subjections of the space dimension according to the user’s need.
2. Structural requirements
   a. Appropriateness of the design to the interaction of the direct user.
   b. Efficiency of the performance of construction materials used in the inner space.
   c. Taking into consideration the environmental climate factors in the selection of materials.

3. Aesthetic requirements
   a. Taking into consideration the aesthetic appearance, commensurate with the culture and environment of the society.
   b. Taking into consideration the choice of interior spaces dimensions and how to furnish them in order to achieve the aesthetics of space.

4. Humanitarian requirements
   a. Taking into consideration the scales of human body in each motion with the scales of interior space.
   b. Taking into consideration the decisions of the space’s user (motional, mental and muscular).

4.3. Dimensions of architectural space
There are three dimensions of the architectural space: [5]
1. The architectural dimension: it means the aesthetic imaging of space and composition.
2. The areal dimension: refers to the standard dimensions of space.
3. The social dimension: how appropriate the space is for the person, socially and psychologically.

4.4. Inner space
The inner space is defined as a part of the outer public space with limitations and specific characteristics, so that a person can practice his private life activities. These activities and their method of performance depend on the nature of the part, its design, its size and its relationship with the outer space around it [6].

4.5. Determinants of inner space
The inner space can be determined by the following;
1. Walls and ceiling
2. Floor
3. Columns
These determinants play a major role in formatting the architectural from of the space and determining its function and its ability to perform the function.

5. Construction materials

5.1. Contemporary construction materials
The construction materials are important in achieving the structure of the architecture, most architectural researches included the importance of construction materials. Most architectural views stated that good construction and good design are using modern construction materials, and those researches emphasized the necessity of producing new materials to fix all architectural and structural problems.
In the 19th century, with the advancement of technology, facilities with multiple and new functions emerged, such as railway stations, factories and company buildings. Evolution has led to the emergence of new construction materials such as iron, steel, glass and concrete. Furthermore, the evolution of science has led to the development of construction methods and the use of different structural parts with large open spaces, so new types of buildings have emerged [7].

5.2. The relationship between construction materials and architecture
There is a good relationship between architecture and construction materials, so materials are chosen depending either on the outer view or on their availability. When the stone was available, it was considered to be the essential construction material for walls because of its durability, availability and accessibility.
Before the nineteenth century, materials used by architects in the design were depending on the function and shape together. However, and with the progress of the industrial revolution, the role of construction material changed, where geometrically studied materials started to be used. It can be said that at the beginning of the nineteenth century, steel structures were widespread, which led to the design and construction of long life and high-rise buildings. At that time, the materials have turned from being a construction material only to a method of work and thinking, which gave the architects wider areas and greater construction potential.

The combination of the glass industry and the development of environmental systems, as well as the construction of lightweight curtain walls, have greatly allowed the possibility of separation in design in the interior building, distribution of rooms and spaces, and the method of loading weights. Therefore, smart materials have emerged, and began to be associated with architecture, such as the materials called photochromic materials, which are the materials that their colour changes according to exposure of light. Whenever the weather was brighter, the colours darker, and vice versa, and that can make a chromatic balance comfortable for the eye. Therefore, smart materials are closely related to architecture due to the ever-changing nature of the architectural facilities, but they are limited at the present time due to the lack of production as well as their expensive price.

5.3. Characteristics of construction materials
The construction materials act as a motivator for architectural design, and help in adopting new styles and ideas by using many methods. The methods of interaction between the designer and construction materials are ranging from the complete surrender of the possibilities of the material to the attempt to show its capabilities and the exploitation of its maximum potentials. So, they become a source of inspiration and can be used without exaggeration, as well as showing the real characteristics of the material. The characteristics of the modern construction materials are [8]:

1. Design characteristics
Modern innovative materials help to achieve the formal ideas of architects. For this goal, the manufacturers have begun to link the technical achievements and scientific experiences with designers' capabilities in order to present modernity in designs.

2. Technical characteristics
The emergence of advanced modern techniques and modern technology has led to ignoring the hand skills that produced multiple styles and entered the local market, so remaining traditional skills have disappeared, which are rich in heritage and traditional handicrafts.

3. Implemental characteristics
As cement and metals are heavy, they overcame the structural problems, and interior finishing works have characterized with durability and high accuracy, due to the design of the most modern materials and innovative details.

4. Expressive and philosophical characteristics
Many productive companies around the world are studying their modern products and working to involve specialists from different fields to provide competitive products that can achieve their objectives. The aesthetic, sensory (colour, touch and gloss) and formative values (size, shape and form) have a key role in the process of material design, production and marketing.

5. Environmental characteristics
The increasing consumption of many natural raw materials has begun to result in a major threat to the environment. Wood and marble are at the forefront of these raw materials. As for the forests, the cutting of trees affected the plant cover, which contributes to the preservation of the environment. Therefore, it was necessary to search for alternative industrial materials instead of for natural materials, or recycling and reusing those materials, such as metals, paper and glass.

6. Formative properties
The formative flexibility of the modern materials, compared to those old and traditional materials, is characterized by the ease of dealing with those products in terms of formative aspects, which are characterized by lightweight, accuracy of manufacture, the durability of construction, and great potential for linking them, whether it is between pieces of similar type and shape.
5.4. The aesthetic effect on contemporary construction materials on architectural spaces
Architectural beauty is defined as the pleasure that can be achieved through the recognition of the design functions and suitability. In addition to the architectural form and the arrangements resulted from architectural formations in the spaces, aesthetic in architecture can be divided into three sections [9].
1. Sensory beauty
2. Emotional beauty
3. Intellectual beauty
   a. Abstract intellectual beauty
   b. Functional intellectual beauty

6. Field study
In this research, the questionnaire is used as a contributory research tool, which used in the collection of preliminary data. A comparison, analysis and interpretation of data were conducted in order to reach acceptable generalizations. The preparation process of the form as well as its validity and consistency to extract results from the questionnaire and general conclusions will be addressed.

6.1. Research methodology
In order to achieve the objectives of the research, a descriptive and analytical approach was used, through which it tries to describe the nature of the research by using a questionnaire and analysing its data and the relationship between its components.

6.2. Research tool
The questionnaire form is considered one of the most widely used and widespread methods of obtaining data from individuals, as it is a tool with dimensions and items that are adopted to obtain opinions and information from the research sample.

6.3. Steps to create the form
1. Identifying the fields to be considered in the form.
2. Reviewing the previous studies and adopting them in creating the form and drafting its paragraphs.
3. Consultation of the specialists and supervisors in determining the dimensions of the form.
4. Identifying the following paragraphs of each field.
5. Presenting the form to number of referees specialized in the field of architecture and construction.
6. Modification of some paragraphs of the form according to the views of the referees, in terms of elimination, addition and amendment, and then use it with the final form. The form consists of two sections:
   Section I: Includes preliminary public data, including (age - gender - education).
   Section II: Consists of 18 terms distributed on four axes:
   a. Effect of construction systems on architectural spaces.
   b. Effect of the used architectural style.
   c. Effect of characteristics of the used construction materials.
   d. Effect of finishing materials in halls.

6.4. Research sample
One hundred twenty-four (124) individuals were selected according to the study variables (gender, education, and years of experience). The distribution of the research sample according to education and years of experience are shown in Table 1 and Table 2, respectively. Table 3 and Table 4 show the percentages of the research sample according to the (gender and education) and (gender and years of experience), respectively.

| Table 1. Distribution of the research sample according to education |
|---------------------------------------------------------------|
| Gender | Bachelor | Master | Doctorate | Total |
|--------|----------|--------|-----------|-------|
| Male   | 46       | 9      | 2         | 57    |
Table 2. Distribution of the research sample according to years of experience

| Gender | Less than 5 years | (5-10) years | More than 10 years | Total |
|--------|------------------|--------------|--------------------|-------|
| Male   | 30               | 12           | 15                 | 57    |
| Female | 24               | 26           | 17                 | 67    |
| Total  | 54               | 38           | 32                 | 124   |

Table 3. Percentages of the research sample according to (Gender and education)

| Gender | Statistics | Bachelor | Master | Doctorate | Total |
|--------|------------|----------|--------|-----------|-------|
| Male   | frequency  | 42       | 9      | 2         | 53    |
|        | percentage | %35.0    | %7.5   | %1.7      | %44.2 |
| Female | frequency  | 50       | 14     | 3         | 67    |
|        | percentage | %41.7    | %11.7  | %2.5      | %55.8 |
| Total  | frequency  | 92       | 23     | 5         | 120   |
|        | percentage | %76.7    | %19.2  | %4.2      | %100  |

Table 4. Percentages of the research sample according to (Gender and years of experience)

| Gender | Statistics | Less than 5 years | (5-10) years | More than 10 years | Total |
|--------|------------|-------------------|--------------|-------------------|-------|
| Male   | frequency  | 30                | 8            | 15                | 53    |
|        | percentage | %25.0             | %6.7         | %12.5             | %44.2 |
| Female | frequency  | 24                | 26           | 17                | 67    |
|        | percentage | %20.0             | %21.7        | %14.2             | %55.8 |
| Total  | frequency  | 54                | 34           | 32                | 120   |
|        | Percentage | %45.0             | %28.3        | %26.6             | %100  |

6.5. Validity of the research tool
Validity is one of the things that are required in the tool to indicate how each of its terms can measure what it has been set to measure, thus the form has been verified.

6.6. Reliability of referees
The questionnaire was presented in a preliminary form to 16 architects and civil referees. Then, they were asked to determine the suitability of the paragraphs that were developed, their clarity, and how much each paragraph is suitable to measure what it was developed to measure. After that, Amendments, observations and additions were taken into consideration, and some paragraphs were eliminated, and then the form was finalized.

6.7. Stability and consistency of the questionnaire
Stability measure steps were performed by using the Cronbach's alpha coefficient. The Cronbach's alpha method was used to measure the stability of the form by using Eq. (1).

\[
\alpha = \frac{n}{n-1} \left(1 - \frac{\sum V_i}{V_t}\right) \tag{1}
\]

Where:
\(\alpha\) = Cronbach's alpha coefficient.
\(n\) = Number of items.
\(V_i\) = Variance of the item scores.
\(V_t\) = Variance of the total scores.
The overall stability of the research was (89%).

6.8. Statistical Analysis

The form was analysed by using the SPSS program (Stochastic Package for Social Science). The following statistical tests were used:
1. Percentage and frequency of the characteristics of the research sample.
2. Cronbach's alpha test to determine the constancy of the form’s paragraphs.
3. Percentages and arithmetic means to analyse the research results.

The total number of forms was (124), but (4) were missed, so the remaining was (120). Percentage of valid forms was (96.8%). The results were presented and discussed according to the questionnaire’s questions, and based on Likert scale, as follows:

To determine the length of the five-point Likert scale’s cells (minimum and maximum), as shown in Table 5, the range was calculated as (5-1= 4), and then it was divided on the highest value in the scale to obtain the cell’s length, (4/5=0.8). After that, this value was added to the lowest value in the scale (the beginning of the scale, which is 1.0) to determine the maximum of this cell, and thus the length of the rest of the cells was found. The minimum and maximum limits of Likert scale used in the research were explained according to the equivalent percentage of each cell and the degree of availability of the requirement.

| Cell length     | Equivalent percentage | Degree of availability |
|-----------------|-----------------------|------------------------|
| 1.0 – 1.8       | 20 % - 36 %           | Very low               |
| More than 1.8 – 2.6 | More than 36% - 52 % | low                    |
| More than 2.6 – 3.4 | More than 52% - 68 % | Medium                 |
| More than 3.4 – 4.2 | More than 68% - 84% | high                   |
| More than 4.2 – 5.0 | More than 84% - 100% | Very high              |

Table 5. Minimum and maximum limits of Likert scale

| No. | Term                                                                 | Arithmetical mean | Standard deviation | Percentage | Rank |
|-----|----------------------------------------------------------------------|-------------------|-------------------|------------|------|
| 1   | The large area of the hall and the large number of prominent columns in it may reduce the physiological comfort. | 4.17              | 0.61              | 83.31 %    | 1    |
| 2   | I like the wide and open hall, without columns, and of a high ceiling. | 3.86              | 0.83              | 77.24 %    | 3    |
| 3   | The abundance of glass and metal partitions creates a feeling that all the joints of the hall are connected with each other. | 3.92              | 0.78              | 78.34 %    | 2    |
| 4   | Narrow hall with many columns and low ceiling may give a very disturbing feeling. | 3.85              | 0.73              | 77.02 %    | 4    |
| 5   | I feel a strong desire to enter the large spacious hall without any column obstructing a good view of | 3.67              | 0.94              | 73.48 %    | 5    |
all the details of the hall.

**Table 7.** Arithmetical mean, standard deviation and percentage of the research sample responses to the second axis (Effect of the used architectural style)

| No. | Term                                                                 | Arithmetical mean | Standard deviation | Percentage  | Rank |
|-----|----------------------------------------------------------------------|-------------------|--------------------|-------------|------|
| 1   | I prefer the hall that the technological development of design and materials are taken into consideration in designing its spaces. I prefer the hall that the design of their spaces keep on the classical ways in materials and design. I prefer the hall in which seating places are of a modern design. | 3.93              | 0.78               | 78.67 %     | 3    |
| 2   | I prefer the hall that the design of their spaces keep on the classical ways in materials and design. I prefer the hall in which seating places are of a modern design. | 4.06              | 0.81               | 81.10 %     | 1    |
| 3   | I prefer the hall that the design of their spaces keep on the classical ways in materials and design. I prefer the hall in which seating places are of a modern design. | 4.00              | 0.74               | 80.00 %     | 2    |

**Table 8.** Arithmetical mean, standard deviation and percentage of the research sample responses to the third axis (Effect of characteristics of the used construction materials)

| No. | Term                                                                 | Arithmetical mean | Standard deviation | Percentage  | Rank |
|-----|----------------------------------------------------------------------|-------------------|--------------------|-------------|------|
| 1   | I have the desire to use some of construction materials to give the hall more luxury in terms of inscriptions and permanence. I have a desire for light colours and gradient between them as finishing for the hall. Consideration of surface and texture of construction materials in the design treatments of hall space. I have the desire for the materials with soft texture in the inner finishing of the hall. I can sense the effect of finishing materials for all inner hall spaces. | 4.06              | 0.70               | 81.22 %     | 2    |
| 2   | I have the desire to use some of construction materials to give the hall more luxury in terms of inscriptions and permanence. I have a desire for light colours and gradient between them as finishing for the hall. Consideration of surface and texture of construction materials in the design treatments of hall space. I have the desire for the materials with soft texture in the inner finishing of the hall. I can sense the effect of finishing materials for all inner hall spaces. | 2.95              | 1.43               | 59.00 %     | 4    |
| 3   | I have the desire to use some of construction materials to give the hall more luxury in terms of inscriptions and permanence. I have a desire for light colours and gradient between them as finishing for the hall. Consideration of surface and texture of construction materials in the design treatments of hall space. I have the desire for the materials with soft texture in the inner finishing of the hall. I can sense the effect of finishing materials for all inner hall spaces. | 4.10              | 0.69               | 82.10 %     | 1    |
| 4   | I have the desire to use some of construction materials to give the hall more luxury in terms of inscriptions and permanence. I have a desire for light colours and gradient between them as finishing for the hall. Consideration of surface and texture of construction materials in the design treatments of hall space. I have the desire for the materials with soft texture in the inner finishing of the hall. I can sense the effect of finishing materials for all inner hall spaces. | 3.03              | 1.24               | 60.5 %      | 3    |
| 5   | I have the desire to use some of construction materials to give the hall more luxury in terms of inscriptions and permanence. I have a desire for light colours and gradient between them as finishing for the hall. Consideration of surface and texture of construction materials in the design treatments of hall space. I have the desire for the materials with soft texture in the inner finishing of the hall. I can sense the effect of finishing materials for all inner hall spaces. | 2.91              | 1.13               | 58.17 %     | 5    |

**Table 9.** Arithmetical mean, standard deviation and percentage of the research sample responses to the fourth axis (Effect of finishing materials in halls)

| No. | Term                                                                 | Arithmetical mean | Standard deviation | Percentage  | Rank |
|-----|----------------------------------------------------------------------|-------------------|--------------------|-------------|------|
| 1   | Cladding of the inner space of the hall with modern finishing materials that have the effect on improving the | 3.88              | 0.72               | 77.68 %     | 3    |
Inconsistency of the finishing materials may negatively affect on using the hall for any occasion.
The inner environment of the hall and its design have a great effect on using the hall for several purposes.
Success or failure of the hall largely depends on the construction materials and finishing materials used.
Inconsistency of finishing materials greatly affects on the use of the hall.

|   |   |   |   |
|---|---|---|---|
| 2 | 4.18 | 0.68 | 83.65 % |
| 3 | 2.65 | 1.13 | 53.00 % |
| 4 | 3.93 | 0.57 | 78.64 % |
| 5 | 2.90 | 1.10 | 58.00 % |

6.9. Conclusion of the questionnaire

**First axis**
According to Table 6.
1. The percentages of all terms were high compared with Likert scale adopted in the research, as shown in Figure 1. (A), and formed a percentage of 100%.
2. Term 1 had large values, the arithmetical mean was (4.17), the standard deviation was (0.61), and the percentage was 83.31%, so this term was ranked first.
3. The lowest arithmetical mean was for term 5, which was 3.67. The standard deviation and the percentage for that term were 0.94 and 73.48% respectively.

Because all terms had a large and very large arithmetical mean, there is an agreement by the sample members on the terms of this axis, and they are able to distinguish and understand the effect of the structural systems on halls.

**Second axis**
According to Table 7;
1. Term 2 was ranked first, with an arithmetical mean of 4.06, a standard deviation of 0.8, and a percentage of 81.10%.
2. All terms of this axis got a large or very large arithmetical mean, according to the answers of the sample’s members, and that indicates to the presence of effect of styles used in the design of halls and the construction materials used.

**Third axis**
According to Table 8;
1. The percentages of all terms ranged between medium and high, as shown in Figure 1. (C).
2. Term 3 was ranked first, with arithmetical mean of 4.10, a standard deviation of 0.69, and a percentage of 82.10%.
3. Term 5 was ranked fifth, with an arithmetical mean (2.91), a standard deviation (1.13), and a percentage of (58.17%).

Final results of the average answers indicate that the research sample is able to distinguish the characteristics of the structural materials used.

**Fourth axis**
According to Table 9;
1. The percentages for all terms ranged between medium and high, as presented in Figure 1. (D).
2. Term 2 was ranked first, with an arithmetical mean of 4.18, a standard deviation of 0.68, and a percentage of 83.65%.
3. Term 3 was ranked fifth, with an arithmetical mean of 2.65, a standard deviation of 1.13, and a percentage of 53.00%. Based on the arithmetical mean of the answers, it was noted that the research sample has realized the effect of construction materials on them to use the hall.

![Graphs showing the percentages of the research sample responses to the four axes of the research.](A), (B), (C), (D)

**Figure 1.** Percentages of the research sample responses to the four axes of the research

7. **General conclusion**
   1. Diversity in construction materials and modern construction systems can provide architectural and structural flexibility for the architectural space, and can participate in the development of the architectural space and make it distinct.
   2. Compatibility between architectural design and structural design works to create a comfortable space, problems-free, and achieve the goal and the function of design.
3. Contemporary construction materials have the ability to meet the desire of users and designers because of the diversity and their characteristics of functional, economical and aesthetical aspects.
4. There is a functional impact of modern construction materials on space through the use of the surface texture of the construction materials in the design solutions of the architectural space.
5. Some construction materials and styles play a significant role in giving the space a distinct luxury, due to the diversity in inscriptions, colours and continuation.

8. Recommendations
1. Need to take advantage of modern technologies, which could use all means to create spaces that provide a suitable environment for space users.
2. Universities and institutes should develop the curricula of finishing materials and modern construction systems.
3. Need to keeping pace with the technical development and follow up the latest findings of science in the field of modern construction materials and construction systems, which helps in the service and development of architectural spaces.

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