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Artificial Lighting Techniques and Structural Expression for Bridges

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Abstract

Bridges are prominent landmarks within the urban landscape. With advancements in bridge design technology, bridges have acquired distinctive expressive values in addition to their functional importance. A wide variety of artificial lighting techniques (Methods are used to produce and manipulate light from non-natural sources) have emerged for bridge illumination. Given the diversity of bridge designs, their application requires an in-depth study. Due to the scarcity of research studies addressing the impact of artificial lighting techniques on enhancing the expressive structural aspects of bridges. This research aims to provide a database on the types and applications of effective artificial lighting techniques in realizing the expressive structural aspects of bridges. This database will assist designers in finding innovative solutions to enhance these expressive features. The impact of artificial lighting techniques on adding new expressive dimensions to bridges has not been studied within the local context, and this is where the originality of the current research lies. The research assumes that artificial lighting techniques have a significant impact on the expressive structural aspects of bridges by enhancing the perception of the structure and adding new expressive dimensions. The study's most significant finding is that the bridge's structural components and elements are the primary drivers for effective and impactful artificial lighting design.

Keywords: Structure of Bridges, Sensory Lighting, Expressive Lighting, Structural Form, Dynamic Structure.

1. Introduction

Bridge design has diversified beyond traditional forms, necessitating the development of modern technologies that emphasize their evolving architectural character. Artificial lighting is one effective

way to highlight the aesthetic appeal of architectural structures at night. Accordingly, this research examines previous studies that have addressed the aesthetics of bridges in general, with particular attention to the application of artificial lighting techniques.

Studies on bridges spanning rivers both ancient and modern have consistently affirmed that structural systems are the primary drivers of bridge aesthetics. Phanchalath and Veerapong (2013) analyzed the development of river-crossing bridges, focusing on engineering and structural aspects with the aim of establishing lighting design approaches. Their study emphasized lighting design standards and concepts that influence bridge elements, using selected samples for analysis [1]. In 2017, Al-Khafaji and Ahmed explored the definition of aesthetics in bridge design, presenting global concepts applied to this topic. They concluded that aesthetics cannot be separated from structural design; in all applied concepts, aesthetics are inherently linked to form, architecture, and artificial structure [2].

Sander's study (2018) examined principles that characterize effective lighting solutions and proposed criteria for evaluating pedestrian bridge lighting design. He also highlighted the importance of identifying individual aspects that must be considered to achieve successful lighting outcomes [3]. Heggade (2021) investigated the aesthetics of bridges, emphasizing conceptual design, bridge technology, and cultural value. He described efficiency, economy, and elegance as common denominators in developing bridge design concepts [4].

Building on these foundations, the present research is unique in classifying artificial lighting techniques according to structural design and applying them to local case studies. It assumes that artificial lighting significantly enhances the expressive structural aspects of bridges by improving perception and adding new dimensions of expression. Within its theoretical framework, the study addresses two main aspects: (1) the structure of bridges, their types, and their structural expression according to the tectonic concept; and (2) the artificial lighting of bridges and the expressive qualities it conveys through different lighting techniques. The practical component applies these theoretical indicators to selected local bridges, using specific criteria to achieve the research aim of providing a database on effective artificial lighting techniques for realizing the expressive structural aspects of bridges.

2. Methodology

The research relied on the descriptive analytical approach to extract the indicators of the theoretical framework, and then adopted the comparative descriptive analytical approach to selected local case studies according to specific criteria that serve the research objective, and then discussed the results and came up with a set of conclusions, as shown in Figure 1.

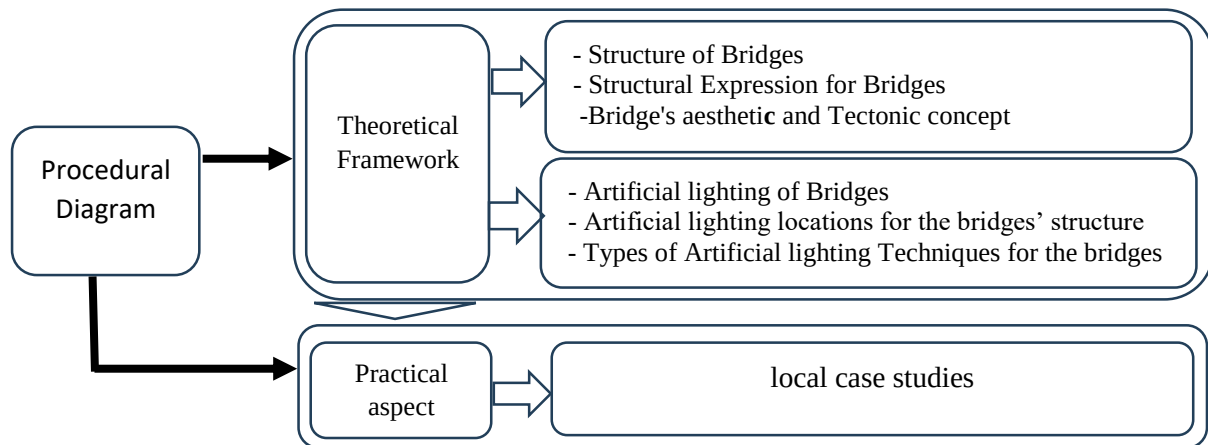


Figure 1. Procedural Diagram of Research

2.1 Structure of Bridges

A successful bridge design should be natural, simple, and in harmony with its surrounding. So aesthetic aspects are not an additional consideration in bridge design, but rather than an integral part of it. Therefore both structural design and aesthetic must be considered during the conceptual design phase. To accomplish this, a bridge designer must have a good understanding of structure and aesthetics of the bridges [5]. Bridges' structures are often classified into several types that differ in the methods of designing the flow of forces.

2.2 Types of Bridges' Structures

Different types of bridges are distinguished by their structure, materials and components, for example a cable-stayed bridge is completely different from a truss or arch bridge [6]. It has been determined that there are four main categories of bridges that cross rivers, according to their structure [1], as shown in Figure 2.

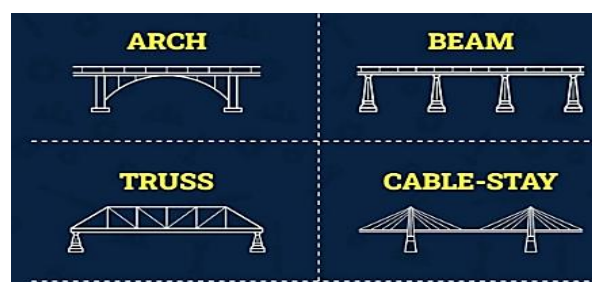


Figure 2. Main Four Bridges according to their structures [7].

2.2.1. Girder bridges (Beam Bridge)

The type of Girder bridges is known as deck-girder bridges, where the girders are designed to be the main component of the superstructure. They carry loads of the slab, including dead and live loads, as well as their own weight and the weight of the membranes. Thus, the beams transfer all these loads to the external supports-pillars- and internal supports-columns. In general, there are two cross-sections of these bridges according to the connection-interfacial layer- between the bridge deck and the girders [8]:

- Monolithic section: when the bridge deck slab and the girders, ribs, or stems are cast simultaneously to form a single section, such as T-beams, and box beams.

- Composite section: when the slab and the girders are cast at different times, and then joined together to form a single section, such as cast-in place (CIP) concrete bridge deck slab with precast concrete girders or steel girders (strings).

2.2.2. Arch bridges

The arch bridge is a strong competitor to the truss bridges in spans up to about 275 meters. If the cost of an arch bridge is equal to or slightly higher, it will be chosen for aesthetic reasons [9].

2.2.3. Truss bridges

The truss bridge behaves similarly to a closed box structure when it has four shear-resistant surfaces and sufficient end gates to transfer shear to vertical loads at the bearings. Because a box-shaped design is needed to resist vertical and lateral loads, the design can be rectangular or triangular, if this geometric shape is suitable for the road elevations [10].

2.2.4. Cable-stayed bridges

Cable-stayed bridge can be classified into three main types [6]: as shown in Figure 3

- Fan System (the fan bridge), which branches out from a central point on the tower.
- Harp System (the lyre bridge), in which the cables are lined up parallel along the length of the tower.
- Semi-Fan System, which branches out from an upper part on the tower.

There may be variation and innovations within these two types, such as the lyre bridge with a side span, a leaning tower, and cables on only one side, a new type used by Santiago Calatrava in the visually stunning Alamillo bridge in Seville [6], as shown in Figure 4.

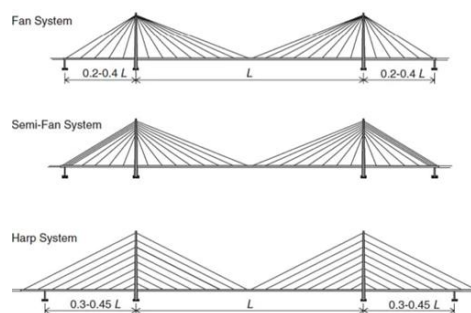


Figure 3. Types of Cable stayed bridge [11]. Figure 4. Alamillo bridge in Seville [6].

2.3 Structural Fundamental of Bridges

Although the four basic structure of bridges - may look very different from each other, each of these bridges types consists of only three basic structural elements, which are:

- The axial elements.
- The bending elements.
- The curved elements.

And by combining these structural elements, different bridge configurations can be formed. For example, axial elements the main consists of a truss bridge, may exist bending moment, but it is secondary. And the same for the cable-stayed bridge. As for the arch bridge, it carries its load through the change in its curvature, and this also applies to the main cables of a suspension bridge. In contrast,

the girder bridge is essentially a bending element [5], as shown in Figure 5, The research suggests that these elements play an active role in the expression of the flow of forces within bridge structure.

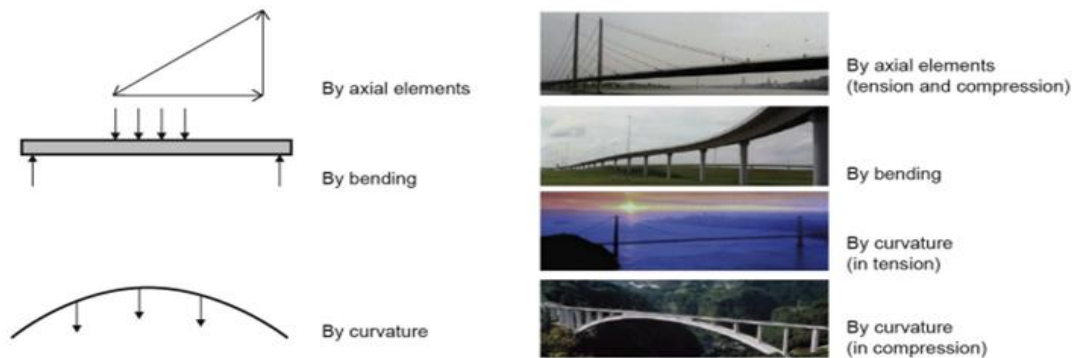


Figure 5. Three basic structural elements [5].

2.4. Structural Expression for Bridges

Bridges are defined as architectural structures which connect communities on opposite bank of rivers. They have gained importance and become as symbols of those places. In the past, engineers designed the bridges primarily for function, not aesthetic purposes. But nowadays, there is an integration between function and aesthetics [12]. As bridges are seen from multiple angles, and people view them from a variety of circumstances, they may be individual objects in a natural landscape, part of a group of structures, or on a street in a city. The presence of the bridge can enhance our perception of the surrounding urban and natural landscape, giving the bridge an additional aesthetic meaning and distinguishing the place at the same time [6]. Tectonics is a fundamental concept in architecture, as it deals with the visual aspects of structure, construction, and materials. So, Tectonics creates a virtual connection between man and his environment, based on his ability to perceive the inspiring link between building and structure, and then to create a harmonious interaction between architecture and people that evokes emotional responses known as empathy [13]. And so, on the Tectonic concept is the best expression for aesthetic bridges' structures.

2.5 Bridge's aesthetic and Tectonic concept

The tectonic in architecture- which refers to the art of structure – has the potential to provides us – during the process of structural design – with a deep structural understanding and detailed spatial perspectives, as a key step toward achieving tectonic architecture. Kenneth Frampton presents seven factors that describe the basic tectonic elements in architecture. These factors are [14]:

- Object: Represent architectural elements, such as columns, wall, ceilings, etc.
- Details: small units that are significant in producing meaning.
- Joint: the connection between the points or elements of structure.
- Material: The cultural expression of the material used.
- Construction: The physical embodiment of the structure.
- Structure: The basic principle of construction.
- Interaction: The harmony between the site, the people, and the architecture.

Tectonics, as a poetic application of structure, embodies an awareness of the meaning inherent in the expressive structural techniques applied, which are appropriate to a specific culture and context, in order to achieve magnificent architecture [15]. Nowadays, In the field of tectonics, the use of modern technology means considering how to employ new techniques, materials, and

construction methods to achieve structural harmony, allowing architecture to produce a new spatial form, based on a close relationship between architecture and the context, and producing an interaction between man, nature, and culture [16]. The research found that modern technologies used in architecture in recent decades have significantly contributed to the creation of a new architectural language embodying the concept of tectonics. And the Artificial lighting is one of these technologies that play important role in expression the form and the flow of forces in bridge structure.

2.6 Artificial lighting of Bridges

The concept of Artificial lighting outdoor was first applied when the city's landmark "Eiffel" was built in 1889, it was first permanent architectural structure for exterior and decorative lighting [17]. There are two essential concept of outdoor Artificial lighting design [18]:

- Illumination for people to use the spaces to achieve Functional Purposes.
- Sensory Perception for holistic awareness of space.

The research will focus on sensory perception as it relates to bridges structural expression, since bridges are one of the clear landmarks within the urban space and are perceived within this context.

The quality of bridge's aesthetic is the reflected of our sensory perception- how it appears to us visually, and this results from fundamentals factors which are [6]:

- Its form, scale, and proportions.
- Its expression of the forces and technology used in it.
- Its strength and durability.
- The relationship of the bridge elements to each other.
- Factors such as texture and color.

One of the related concepts, is the concept of Harmony, which is the sense of the visual balance, and the compatibility of parts and elements within structure, in addition of the harmony with the surrounding environment [19]. As the bridges are an integral part of the site and place, must be in harmony with their context, so they can shape the place or define its identity [6]. Figure- background is one of the roles that reflect sensory perception which plays essential role in activation of artificial Lighting and appears clearly in Bridges' Architecture. Bridges are often seen against a dark night sky. They are typically viewed from a different perspective, as a dark background like a river. The concept of Sensory Perception focuses on two main aspects [20]:

- **Sensory Lighting:** This type of Lighting focuses on sensory experiences and the perception of space through Light. It deals how the properties of Lighting – its intensity, direction and color – interact with materials, forms, and sizes in the architectural environment to influence spatial perception and cognitive performance of man in different ways.

Light is more than a utility. It is a language that architects and designers use to write stories in space. Light influences how we interpret spatial geometry, materiality, and orientation. In this way, light becomes an architectural linguistic construct, expressing the identity of the place [21].

- **Expressive Lighting:** A type of Lighting used as a means of artistic expression and communication. These types of effects not only illuminate the space, but also give it a new dimension of meaning and the Communication of ideas, the telling of stories, or the highlighting of specific architectural features. So, this style is characterized by its creativity and its ability to evoke strong feelings and deep emotional responses - It allows designers and artists to go beyond basic functions and harness the power of light to transform and bring spaces to life – by

combining creativity with technology, any environment can be transformed into a dynamic, interactive work of art, as shown in Figure 6, [20].

The research confirms that sensory lighting emphasizes on structure perception which involve both structural expressive form, and expression of the flow of forces. While Expressive Lighting emphasizes on generate of new dimension for expressive structure which reflecting the vision of the dynamic Structure. In order to embody these concepts in bridges' structure, it is necessary to highlight the most prominent artificial lighting Techniques for the bridges.



Figure 6. Infinity Bridge in Stockton-on-Tees, composed of two asymmetrical arches. Its name derives from the water reflection that creates an infinity symbol [22].

2.7 Artificial lighting locations for the bridges' structure

Different approaches have been adopted in the design of bridges' artificial lighting, for Hntb Corporation their classification was according to [23]:

- Superstructure type and shape (Vertical and horizontal geometry and their relationship to the surrounding environment),
- Piers, placement and shape,
- Abutment placement and shape (Interaction between the bridge and its surroundings environment)

While, Suriyothin, and Eawpanich, confirmed that there are three main architectural elements that go into lighting design, which include the superstructure, the bridge deck, and piers.

Furthermore, Collins and Chapman their classification depends on the parts of bridges like:

- Superstructure: Parapet, Girder
- Substructure: Headstocks (transfer loads from several beams to the support column), Piers (A balance needs to be achieved that responds to the best structural form), Pile caps Since piers are essential for supporting piers in soft soil, pier caps are a distinctive feature of bridges that cross waterways. It also presents an aesthetic challenge, as it forms the basis of the pavement, Abutments, as shown in Figure 7.
- Details: It is the details that determine success or failure of a design, and this applies specially to bridges where details are clearly visible. There are main aesthetic considerations in bridge design:
 1. The aesthetics of the bridge details must be considered as an integral part of its overall design.
 2. The design of the details should reduce the potential of stains occurring.
 3. The details of the bridge should not affect the whole form of the bridge.
- Joints and connections: Connections in bridge structures, whether at span ends or along the superstructure, are an opportunity to improve bridge design and add an extra level of detailed aesthetics.

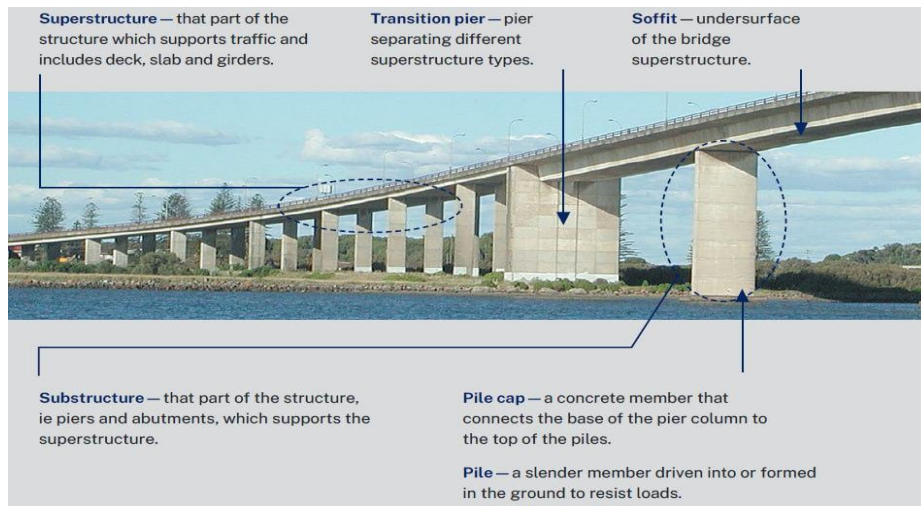


Figure 7. The parts of bridge's structure [6].

The research will be based on classifying bridge structures into superstructure and substructure, which serves as an effective indicator in selecting the location and type of artificial lighting techniques to translate structural concepts.

2.8. Types of Artificial Lighting Techniques for the bridges:

2.8.1 String lighting: Although the fields of string lighting and bridge design are very different – one focusing on aesthetics and the other on engineering- there are fundamental principles that connect them. Both reflected continuous systems adaptable design, and a thoughtful distribution of forces, whether it is loading distribution in bridges or power distribution in lighting. In addition, both contribute to the overall visual and functional harmony of the space. Highlighting how different design elements in architecture- whether structural or decorative- can work together to create a cohesive experience [24].

2.8.2 Rope lighting: They are flexible cylindrical strings containing small LED lights encased in a transparent or frosted tube. Rope lighting can be shaped or bent to follow curves and lines, making them ideal for directional lighting. They are often used to define or highlight the structure of a bridge, due its flexibility, it can wrap around cables creating continuous lines of light. so, it defines the form of the bridge at night. It provides diffused light ideal for aesthetic purposes [24]. So, String lighting and Rope lighting techniques mostly used in lighting the axial elements of the bridges' superstructure due their continuity and flexibility, see Figure 8 and 9.

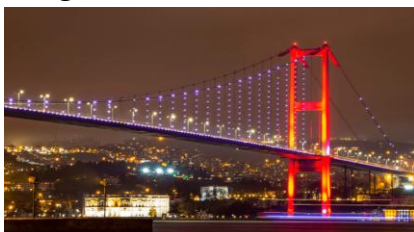


Figure 8. The Bosphorus Bridge, in Istanbul, Turkey, (String lighting) [25].



Figure 9. Dubai Meydan Bridge (Rope lighting) [26].

2.8.3 Wall washing: involves lighting techniques that spread light evenly over a vertical surface to create uniform lighting. This can be achieved using a series of spotlights or other-directed light sources. Wall washing technique can be used on the vertical elements of the bridge, such

as bridge piers, abutments, or the bridge itself. It provides even lighting that highlights the bridge's texture, structure, and mass. Provides soft, even lighting, ideal for highlighting architectural elements without creating harsh shadows, ideal for highlighting large, flat surfaces [27]. For example, Sheikh Zayed Bridge designed by Zaha Hadid, the lighting design is based on two principles: the first is a metaphor for the flow of energy through water, where colored light fades from one shade to another as it moves along the bridge's pillar. The second principle is that the lighting gives the bridge's pillar a three-dimensional appearance at night by projecting different colors onto horizontal and vertical surfaces, thus highlighting the pillar's spatial structure [28], as shown in Figure 10, Wall washing is often used to expand the perceived size of a space, highlight the texture or color of the surface [29]. So, Wall washing technique mostly used in the bending elements and extensive Surfaces of the bridges due to the uniform lighting that have been created.

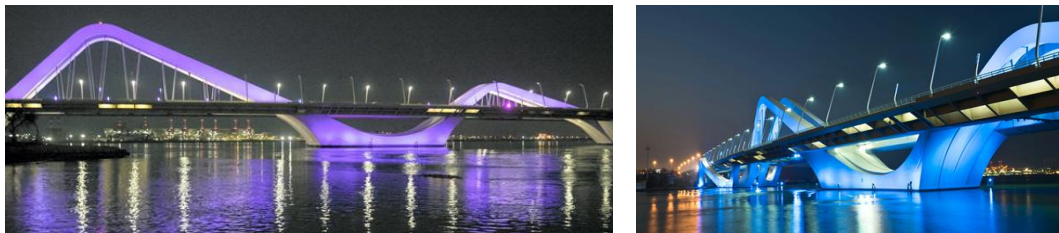


Figure 10. Sheikh Zayed Bridge, Abu Dhabi, UAE, designed to emphasize its unique architectural form. [28].

2.8.4 Up Lighting: refers to the technique of placing light sources at ground level and directing them upwards to illuminate vertical surfaces or elements. It can be used to highlight the underside of a bridge deck or supports, creating visual effects. It is ideal for highlighting the grandeur of bridge, especially suspension or cable-stayed bridges, where the underside is impressive [30], as shown in Figure 11.

2.8.5 Down Lighting: Involves placing light sources above an object and directing the light downwards to illuminate the space or surface below it. It is useful for illuminating the bridge road itself or pedestrian walkways. They can also be used on the tops of bridge supports to create a highlighting effect on specific parts of the bridge below [30], as shown in Figure 12.

So, Up Lighting and Down Lighting technique mostly used in the vertical elements of superstructure and substructure of the bridges due to the directed visual effects that have been created.



Figure 11. Pinellas Bayway Bridge (up lighting) [11]



Figure 12. Busan Harbor Bridge – South Korea (Downlighting) [31]

As a result, the research concluded that there are several primary and secondary indicators derived from the theoretical framework, organized, as shown in Table (1), which are tested in the practical application.

Table 1 Primary and secondary indicators.

Aspects of Perception	Expressive Structure	Location of Artificial Lighting Techniques	Types of Artificial Lighting Techniques
Sensory Lighting (Structural Perception)	The structural expression Form	Superstructure	String lighting, Rope lighting, Up Lighting, Down Lighting, Wall washing
		Substructure	Wall washing, Down Lighting
	The expression of the flow of forces	The axial elements	String lighting, Rope lighting,
		The bending elements	String lighting, Rope lighting,
		The curved elements	String lighting, Rope lighting,
Expressive Lighting (Generate of new dimension for expressive structure)	Reflecting the vision of the Dynamic Structure	Superstructure	String lighting, Rope lighting, Up Lighting, Down Lighting, Wall washing
		Substructure	Wall washing, Down Lighting

2.9 Practical aspect: case studies

A selection of local examples was chosen to test the research hypothesis and achieve its object. The selected examples were chosen according to the following criteria:

- All examples are major bridges in Iraq and are considered prominent landmarks within their urban environments.
- The bridges exhibit diversity in their structural design.
- The artificial lighting techniques used are clearly visible.
- The methods employed in utilizing artificial lighting techniques are varied

2.9.1 4th of July Bridge (Suspension Bridge) in Baghdad – 1964

The bridge spans the Tigris River in southern Baghdad and is one of the oldest suspension bridges in the Middle East. It was designed by the American engineer David B.Steinman, and constructed by a Belgian company. The bridge connects the Karkh side of the Tigris River to the Karrada Sharqiya district on the Rusafa side [32], as shown in Figure 13 and Table 2.

**Figure 13. Artificial Lighting Techniques of 14th of July Bridge.**

2.9.2. Al-Sarafiya Bridge in Baghdad, built 1952, rehabilitation 2008

The bridge spans the Tigris River in Baghdad. Popularly Known as the Iron bridge. It is the oldest bridges in the area. Construction began in 1948 by the Iraqi government, contracted to the British company Holloway. Al-Sarafiya bridge connects the Al-Waziriyah district of Al-Adhamiyah with Al-Atifiyah district of Al-Karkh. [32], as shown in Figure 14 and Table 3.

Table 2. Primary and secondary indicators for 14th of July Bridge (Suspension Bridge)

14th of July Bridge (Suspension Bridge) in Baghdad	Aspects of Perception	Expressive Structure	Location of Artificial Lighting Techniques	Types of Artificial Lighting Techniques
	Sensory Lighting (Structural Perception)	The structural expression Form	Emphasis on the main vertical structure (towers), Emphasize each series of cables	String lighting, Rope lighting, Wall washing
			Emphasize the piers	Up Lighting
		The expression of the flow of forces	Emphasize all axial elements of Each series of cables	String lighting
			Emphasize the bending elements	Rope lighting
	Expressive Lighting (Generate of new dimension for expressive structure)	Reflecting the vision of the Dynamic Structure	Reflected color vision of the outline form of the bridge, and the series of cables and verticals of elements	String lighting, Rope lighting, Wall washing
			It is almost non - existent	Up Lighting

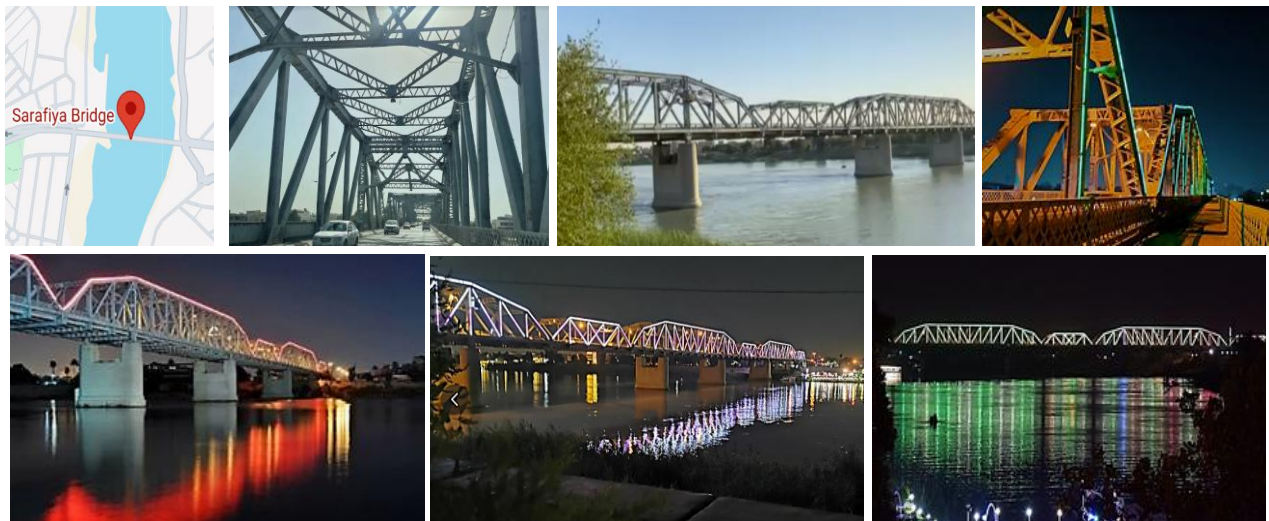


Figure 14. Artificial Lighting Techniques of Al-Sarafiya Bridge.

Table 3. Primary and secondary indicators for Al-Sarafiya Bridge.

Al-Sarafiya Bridge in Baghdad	Aspects of Perception	Expressive Structure	Location of Artificial Lighting Techniques	Types of Artificial Lighting Techniques
	Sensory Lighting (Structural Perception)	The structural expression Form	Emphasize the outer line of the superstructure	Rope Lighting
			-	-
		The expression of	Emphasize all axial elements of bridge's truss	Rope Lighting

	Expressive Lighting (Generate of new dimension for expressive structure)	the flow of forces	Emphasize the bending elements	Rope Lighting
			-	-
		Reflecting the vision of the Dynamic Structure	Reflected vision from truss	Rope Lighting
			Absence of the reflected vision from piers	-

2.9.3. Al-Hadarat Bridge in al Nasiriyah – 2016

The bridge spans the Euphrate river, connecting the Al-Jazira and Al-Shamiyah sides. Constructed by the French company Mater, it is linking the two banks of the Euphrates and the center of Nasiriyah city. The bridge has two lanes for each direction and is considered a vital artery for the city due to its strategic location [32], as shown in Figure 15 and Table 4.



Figure 15. Artificial Lighting Techniques of Al-Hadarat Bridge.

Table 4. Primary and secondary indicators of Al-Hadarat Bridge

Al-Hadarat Bridge in al Nasiriyah	Aspects of Perception	Expressive Structure	Location of Artificial Lighting Techniques	Types of Artificial Lighting Techniques
	Sensory Lighting (Structure Perception)	The structural expression Form	Emphasis on the main vertical structure (towers), Emphasize each series of cables	Up Lighting, Rope Lighting
			-	-
		The expression of the flow of forces	Emphasize all axial elements of Each series of cables	Rope Lighting
			Emphasize the bending elements	Rope Lighting
	Expressive Lighting (Generate of new dimension for expressive structure)	Reflecting the vision of the Dynamic Structure	-	-
			Reflected color vision of the outline form of the bridge	Rope Lighting
			-	-

2.9.4 Al-Saray Suspension Bridge in Maysan – 2017

The bridge spans the Tigris River in Amarah. It connects Tigris Street and the Saray Corniche near the Maysan Governorate building to the Al-Ardhat area and Baghdad Street. The bridge was

constructed by the Iraqi company Anwar Suri, with designs developed by an engineering consultancy firm in collaboration with a German engineering consultancy. [32], as shown in Figure 16, Table 5.

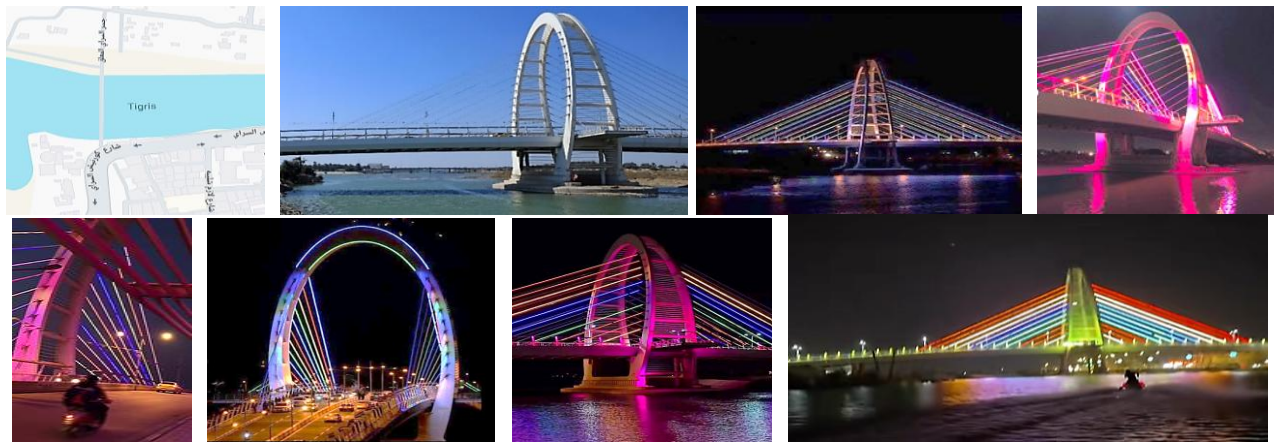


Figure 16. Artificial Lighting Techniques of Al-Saray Suspension Bridge.

Table 5. Primary and secondary indicators of Al-Saray Suspension Bridge

Al-Saray Suspension Bridge in Maysan	Aspects of Perception	Expressive Structure	Location of Artificial Lighting Techniques	Types of Artificial Lighting Techniques
	Sensory Lighting (Structural Perception)	The structural expression Form	Emphasize the arch, Emphasize each series of cables	Up Lighting, Rope Lighting
			Emphasize the piers	Up Lighting
		The expression of the flow of forces	Emphasize all axial elements of Each series of cables	Rope Lighting
			Emphasize the bending elements	Rope Lighting
			-	-
	Expressive Lighting (Generate of new dimension for expressive structure)	Reflecting the vision of the Dynamic Structure	Reflected color vision from arch and the series of cables	Up Lighting, Rope Lighting
			Reflected color vision	Up Lighting

2.9.5 Italian Bridge in Basra - 2017

The bridge spans the Shatt al-Arab waterway, where the Tigris and Euphrates rivers meet, connecting the Shatt al-Arab district with the city center of Basra. It is known as the New Tanuma bridge. Constructed by the Italian construction company MEAG. Includes a navigational crossing, it is the widest bridge in Iraq [32], as shown in Figure 17, Table 6.



Figure 17. Artificial Lighting Techniques of Italian Bridge.

Table 6. Primary and secondary indicators of Italian Bridge

Italian Bridge in Basra	Aspects of Perception	Expressive Structure	Location of Artificial Lighting Techniques	Types of Artificial Lighting Techniques
	Sensory Lighting (Structural Perception)	The structural expression Form	Emphasis on the main vertical structure (tower)	down Lighting, up lighting
			Emphasis on the piers	Wall washing
		The expression of the flow of forces	-	-
			Emphasis on the bending element	String lighting
	Expressive Lighting (Generate of new dimension for expressive structure)	Reflecting the vision of the Dynamic Structure	Reflected vision from tower Absence of the reflected vision from cables	String lighting, Rope lighting, Up Lighting
			Reflected vision from piers	Wall washing, Down Lighting

3. Results and Discussion:

According to the analytical study of the selected examples and based on the primary and secondary indicators derived from the theoretical framework, as shown in, table 7, 8. Following points were found:

Table 7. Comparative descriptive analytical for Sensory Lighting to selected case studies.

No.	Bridge's Name		Aspects of Perception													
			Sensory Lighting (Structural Perception)													
			The structural expression Form						The expression of the flow of forces							
			Location of Artificial Lighting Techniques	Types of Artificial Lighting Techniques					Location of Artificial Lighting Techniques	Types of Artificial Lighting Techniques						
				String lighting	Rope lighting	Wall washing	Up Lighting	Down Lighting		String lighting	Rope lighting	Wall washing	Up Lighting	Down Lighting		
1	14th of July Bridge (Suspension Bridge) / Baghdad		Superstructure	Emphasis on the main vertical structure (towers), Emphasize each series of cables	●	●	●			The axial elements	Emphasize all axial elements of Each series of cables	●				
										The bending elements	Emphasize the bending elements		●			
			Substructure	Emphasize the piers				●		The curved elements	—					

2	Al-Sarafiya Bridge / Baghdad	Superstructure	Emphasize the outer line of the superstructure		●				The axial elements	Emphasize all axial elements of bridge's truss		●			
									The bending elements	Emphasize the bending elements		●			
		Substructure	—						The curved elements	—					
3	Al-Hadarat Bridge / al Nasiriyah	Superstructure	Emphasis on the main vertical structure (towers), Emphasize each series of cables		●		●		The axial elements	Emphasize all axial elements of Each series of cables		●			
									The bending elements	Emphasize the bending elements		●			
		Substructure	—						The curved elements	—					
4	Al-Saray Suspension Bridge / Maysan	Superstructure	Emphasize the arch, Emphasize each series of cables		●		●		The axial elements	Emphasize all axial elements of Each series of cables		●			
									The bending elements	Emphasize the bending elements		●			
		Substructure	Emphasize the piers				●		The curved elements	—					
5	Italian Bridge / Basra	Superstructure	Emphasis on the main vertical structure (tower)				●	●	The axial elements	—					
									The bending elements	Emphasis on the bending element	●				
		Substructure	Emphasis on the piers			●			The curved elements	—					

Table 8. Comparative descriptive analytical for Expressive Lighting to selected case studies.

No.	Bridge's Name	Aspects of Perception						
		Expressive Lighting						
		(Generate of new dimension for expressive structure)						
		Reflecting the vision of the Dynamic Structure						
		Location of Artificial Lighting Techniques		Types of Artificial Lighting Techniques				
				String lighting	Rope lighting	Wall washing	Up Lighting	Down Lighting
1	14th of July Bridge (Suspension Bridge) / Baghdad	Superstructure	Reflected color vision of the outline form of the bridge, and the series of cables and verticals of elements	●	●	●		
		Substructure	It is almost non - existent				●	
2	Al-Sarafiya Bridge / Baghdad	Superstructure	Reflected vision from truss		●			
		Substructure	Absence of the reflected vision from piers					
3	Al-Hadarat Bridge / al Nasiriyah	Superstructure	Reflected color vision of the outline form of the bridge		●			
		Substructure	—					
4	Al-Saray Suspension Bridge / Maysan	Superstructure	Reflected color vision from arch and the series of cables		●		●	
		Substructure	Reflected color vision				●	
5	Italian Bridge / Basra	Superstructure	Reflected vision from tower Absence of the reflected vision from cables	●	●		●	
		Substructure	Reflected vision from piers			●		●

1 -The artificial lighting techniques used on the 14th of July Bridge in Baghdad emphasized the main vertical structural elements (tower) and cables. The use of artificial lighting techniques with diverse color gave the bridge a dynamic and highly expressive structural character. At the same time, the artificial lighting techniques did not focus on the substructure (piles), resulting in their lack of visibility in the reflection on the Tigris River, which contributed to the perception of it as a floating bridge .

2 -A single technique was used in Al-Sarafiya bridge in Baghdad, to emphasize the overall form and secondary elements (superstructure). This clearly highlighted the force paths within the bridge's metal structure-axial elements. Which is a successful approach considering the bridge's age, and its connection to the collective memory of the community. The artificial lighting techniques did not focus on the sub structural elements (piles) resulting in their lack of visibility in the water's reflections, which contributed to the perception of the bridge as a floating structure. The structural expression of the bridge is developed by emphasizing the horizontal element and employing the string lighting technique.

3 -The artificial lighting techniques on the Bridge of Civilization in Nasiriyah, were limited to the bridge's vertical elements (superstructure) and cables, employing a single technique. The height of the piling above the Euphrates River is relatively small compared to the vertical part (towers), thus the focus became on the bridge's horizontal orientation. To develop the structural expression of the bridge, it would have been possible to give greater importance to the main vertical elements by adopting the wall washing technique with a contrasting color.

4 -The artificial lighting techniques appeared in the Saray bridge in Maysan, emphasize the main element of the structure (the arch), creating a colorful visual effect on the surface of the Tigris River and giving new expressive values to the surroundings. The lighting also emphasizes the cables with diverse color effects using the rope lighting technique The structural expression of the bridge is enhanced by standardizing the color of the cables to give a stronger expression to the paths of forces.

5- The use of artificial lighting techniques in the Italian bridge in Basra, was primarily on the vertical structural elements (superstructure - the towers), and (substructure - the piers). Because the bridge is located on the Shatt al-Arab waterway, a vital shipping lane, the ratio of the piers to the towers, is almost equal, thus giving them a dominant presence in the overall design. The lack of variety in artificial lighting techniques, coupled with the absence of emphasis on cables, meant that reflections were limited to the vertical sections.

So, that confirms the research hypothesis, that the artificial lighting techniques have a significant impact on the expressive structural aspects of bridges by enhancing the perception of the structure and adding new expressive dimensions.

4. Conclusions

Based on the findings of this study, several key conclusions can be drawn regarding the relationship between bridge structures and artificial lighting design:

1- The effects of artificial lighting design must align with the structural design of the bridge, as the bridge's structural components and elements are the primary drivers for effective and impactful artificial lighting design.

2 -Adopting the concept of hierarchical progression in the artificial lighting design, in accordance with the hierarchy of the bridge structure, as it is one of the effective things, in the harmony and integration of the structural design with the design of artificial lighting.

3 -The reflection achieved through the appropriate design of artificial lighting on the water's surface contributes to creating three-dimensional effect, and a clear sense of depth with impactful visual extensions, while providing vitality and dynamism to the urban scene.

4 -The bridge's form is determined by the selection of its main structure, which is the focus of the design process. Artificial lighting must therefore emphasize the embodiment of the structural concept through the variety of lighting technologies employed.

5 -The use of color variation adds dynamic to the structure and helps generate new dimensions of architectural expression. Adopting the mechanism of color change-moving lighting- allows for diversity and adds new meanings that contribute to enhancing the concept of dynamic.

6 -The bridge is clearly understood in the law of figure and background by adopting the design of artificial lighting, as the background is the dark sky. The overall form of the bridge is perceived, and consequently, the structural elements and their relationship with surroundings are clearly understood.

7- Artificial lighting techniques add new meanings and functions to the bridge. Some parts of the bridge are now utilized for recreational purposes, such as fishing platforms, as seen in the Maysan Bridge. Furthermore, they facilitate pedestrian movement for recreational purposes.

5. Recommendations

In light of the study's findings, the following recommendations are proposed to guide future bridge design practices and ensure effective integration of artificial lighting techniques:

1- Adopting the principles of integration between architectural design, structural design, and electrical services design, starting from the initial stages of the bridge design process.

2- Given the rapid advancements in artificial lighting techniques, architects must be familiar with the latest technologies and their applications within bridge designs.

Declaration of generative AI and AI-assisted technologies in the writing process

-None

Disclosures

The authors have no conflicts of interest to declare in relation to this manuscript.

Abbreviations

The following abbreviations are used in this manuscript:

CIP Cast-in Place

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تقنيات الإنارة الاصطناعية والتعبيرية المنشئية للجسور

الخلاصة: تعد الجسور إحدى المعالم الحضارية البارزة ضمن المشهد الحضري للمدينة، ومع التقدم التكنولوجي للتصميم المنشئي للجسور، أصبحت الجسور لها قيم تعبيرية مميزة، فضلاً عن أهميتها الوظيفية، ظهر تنوع كبير في تقنيات الإنارة الاصطناعية (وهي الطرق المعتمدة لتوفير الإنارة من مصادر غير طبيعية)، والمستخدم في إنارة الجسور، ونظراً لتنوع التصميم المنشئي للجسور أصبحت عملية توظيفها تحتاج إلى دراسة مستفيضة. وبسبب قلة الدراسات التي تناولت أثر تقنيات الإنارة الاصطناعية على تعزيز الجانب التعبيري المنشئي للجسور، فجاء البحث ليهدف إلى توفير القاعدة المعلوماتية حول نوع وموقع تقنيات الإنارة الاصطناعية الفاعلة في تجسيد الجانب التعبيري المنشئي للجسور والتي تساعد المصممين على إيجاد الحلول المبتكرة لتعزيز الجوانب التعبيرية المنشئية. إن تأثير تقنيات الإنارة الاصطناعية على إضافة أبعاد تعبيرية جديدة للجسور لم تدرس ضمن السياق المحلي وهنا تكمن الإصالة في البحث الحالي. يفترض البحث أن لتقنيات الإنارة الاصطناعية تأثير فاعل في التعبيرية المنشئية للجسور عن طريق إدراك الهيكل الإنشائي مع إضفاء قيم تعبيرية جديدة. أبرز ما افترضته الدراسة أن أجزاء وعناصر الجسر المنشئية هي المحرك الرئيس لتصميم فاعل ومؤثر للإنارة الاصطناعية.

الكلمات المفتاحية: الهيكل المنشئي للجسور، الإنارة الحسية، الإنارة التعبيرية، شكل الهيكل المنشئي، ديناميكية الهيكل المنشئي.