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Formal Transformations in Islamic Building Design and Their Sustainable Impact on Contemporary Architecture

Zainab Hamid Mohson[1], Zeyad Ali Ismael[2], Shoula Raad Naiem[3], Saba Salih Shalal[4]

Abstract

Form is one of the fundamental aspects associated with the evolution and change in architecture, where formal transformations can be understood as a series of processes that change the formal system to achieve new forms that suit the surrounding conditions. This is shown through the succession of appearances and evolution of forms in response to changing environmental and cultural factors. This study addresses the impact of morphological transformations on the designs of Islamic buildings, where the research problem lies in the lack of a clear understanding of how these transformations affect Islamic architecture and their future impact on modern-day architecture. The study is based on the hypothesis that the application of a set of formal transformations to the styles of Islamic buildings has contributed to the enhancement of sustainable aspects in contemporary architecture. To achieve this, the research dealt with the study of patterns of formal transformation and the comparison of architectural forms to measure their effects on sustainability. The study touched on multiple levels of transformation: total, partial, and transformation mechanisms, and reached practical application through the analysis of three architectural models: Two of the Islamic architecture of the Abbasid era (Al-Akhidar Fort and the Al-Mustansiriya School), and the third of contemporary architecture (the Louvre Museum in Abu Dhabi).

Keywords: *Contemporary Architecture, Formal transformations, Islamic buildings, regular transformations, transformation mechanisms, transformation, sustainability.*

Introduction

Transformations are continuous and unending processes as long as life persists through its various historical stages. Transformation is an indispensable factor for any aesthetic system, and the greater the transformation, the more significant the impact, provided that the system remains intact. The term 'transformation' consists of two concepts: 'trans,' meaning change, and 'form,' which relates to shape. Together, they convey meanings such as changing form, appearance, nature, or property[1,2].

The principle of comparison between forms is based on mathematical foundations, where the shape is assumed to be converted into a set of numbers and the relationships between them. This method allows for the description of Formal transformations resulting from these relationships and identifies the changes that occur to forms during the stages of growth and development [3].

There are two types of Formal transformations resulting from specific procedures:

1. Regular Transformations: These are transformations that result from uniformly scaling the length and width, producing a grid of equally sized rectangular units [3].
2. Irregular Transformations: In this case, the expansion or contraction of one of the dimensions (length or width) occurs at unequal ratios, producing a grid of unequal and non-identical units n[3].
3. Weinberg noted the existence of two types of transformations: the first leads to the preservation of the type for a group of generated forms, while the second leads to the emergence of new types, as illustrated in Figure 1 from a study. This figure shows the relationship between the

[1]Electrical Engineering Technical College, Middle Technical University, Baghdad 10074, Iraq. Corresponding Author Email: zainab.hamidqq@mtu.edu.iq
[2] College of Physical Planning, University of Kufa, Al Najaf 54003, Iraq.
[3] University of technology, construction and projects department , Baghdad 10066, Iraq
[4] Department of Architecture, College of Engineering, University of Kerbala 56001, Iraq; Department of Architecture, Al Safwa University College, karbala 56001, Iraq

environment, transformations, and distinct variables that reflect the properties of survival and continuity of the system, which helps in identifying the distinctive variables (**Figure 1**)[4].

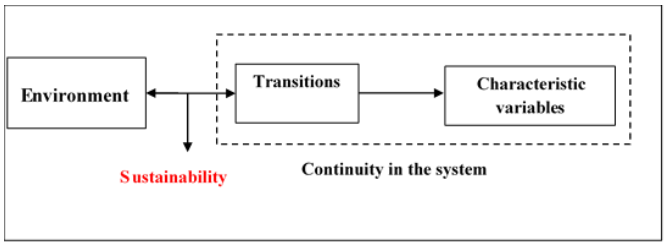

Figure 1 illustrates the relationship between the environment and transformations (Ahmed et al., 2024)

In epistemology, the concept of transformation is interpreted as a change in a specific code. This transformation encompasses meanings of modification, reordering, and regrouping, which serve as mechanisms for transformation. Additionally, architecture, as one of the most significant social phenomena, has begun to be influenced by the concept of transformation. Contemporary theorists have shown a clear interest in this concept and its potential to be leveraged in the development of design theories and strategies[5–7].

The continuous search for identity within the built environment will lead some forms to undergo constant transformation, as these forms are collectively chosen as mediums expressing the identity of their users. A change in form does not necessarily imply a loss of identity; human groups often wish to outwardly express the spirit of the era they live in through the use of forms that represent the technologies of that time, even if these forms remain traditional in their values. For instance, the gateway of a residence is a significant form in all human cultures[8,9].

There is a universal agreement on its visual and symbolic value, reflecting the social and economic status of the homeowner. However, each culture has its own way of expressing these values and meanings, and even within a single culture, there are clear differences in the styles of residential gateways. Each family may seek uniqueness through the design of its gateway. A study of the evolution of residential gateways over a specific period would likely reveal a gradual transformation, with the form at the beginning of the period being entirely different from the one at the end, despite the latter being a result of the evolution of the former[10,11].

The study noted that E. Hirsch explained this phenomenon by pointing out two mechanisms for the gradual transformation driven by the search for identity. The first mechanism is "Qualitative Continuity," where an entity remains qualitatively constant over time or undergoes qualitative changes throughout time. In this context, we can say that the continuous qualitative transformation in the urban structure represents a series of small changes occurring in the built environment as people begin to select potential visual and spatial settings to express their individual and collective values. The second mechanism is "Spatiotemporal Continuity," which means that the location occupied by an entity changes over time[12].

Similar to qualitative continuity, spatiotemporal continuity is characterized by a continuous movement composed of small shifts in the entity's location. Upon closer examination of the urban environment, tracing some of these forms back to their origins and following their historical development reveals many gradual transformations they have undergone [13].

The apparent relationships indicate that transformations at the superficial level are more evident than those at the fundamental level. Architects have focused on two patterns of transformation at the level of elements (components)[14].

In the first pattern, architects tend to apply transformation to a part of the adopted form, particularly in shapes derived from outside the field of architecture, as transforming the entire form in this case would disconnect it from the audience. In the second pattern, the transformation is applied to the whole form when the shape belongs to the field of architecture, as the transformation does not cause it to lose its connection with the audience within certain limits (these limits may reach a maximum where communication with the audience becomes completely severed). It has become clear that there are two types of transformation over time: the first involves extended time, and the second involves discontinuous time. This distinction is due to architects adopting a single form in the case of extended time, resulting in a phased transformation, with the time extending over sequential stages. In contrast,

in the case of discontinuous time, the transformation occurs across multiple forms from different references[14,15].

Formal transformations in Islamic architecture open up new horizons in contemporary architectural design, where modern materials, such as reinforced plastics and composites, can be used to re-interpret traditional patterns in more sustainable ways. This approach contributes to reducing the consumption of natural resources, minimizing waste, and improving energy efficiency by incorporating smart design elements, such as natural ventilation and advanced thermal insulation. The use of lightweight and recyclable materials also allows for more flexible and sustainable structures, which contributes to reducing the carbon footprint of buildings. Through this fusion of technology and architectural identity, a contemporary urban environment is achieved that reflects Islamic aesthetic values while meeting sustainability requirements and adapting to future challenges[16].

The combination of the glass industry with the development of environmental systems has allowed the so- called (world-class) or transparent architecture that can be built anywhere and under any climate. Then it turned to the so-called smart materials, starting from the nineteenth century until now, where the architect had previously used traditional building materials such as stone and wood with their advantages and disadvantages together. Then the science of building materials developed and these materials became adjustable in their properties to suit the design proposed by the architect.[17]

Applied Study of Morphological Transformations in Islamic Building (AL-UKHAIDIR FORTRESS AND AL-MUSTANSIRIYA SCHOOL)

This study will present three samples for the analysis and measurement of the criteria for achieving morphological transformations derived from the theoretical framework, which will be detailed (Table 1), The study will measure a set of variables at levels related to the elements of the theoretical framework. The research employs a descriptive-analytical approach, allowing the researcher to analyze the phenomenon under study. Upon completing the examination of these buildings, the researcher will determine whether the elements align with the framework (based on the plans and information available for each building).

Al-Ukhaidir Fortress in Karbala

The Al-Ukhaidir Fortress is a unique, imposing structure renowned for its architectural and decorative artistry, expansive spaces, and massive structure. It is located approximately 50 km southwest of Karbala and about 152 km southwest of Baghdad (Figure 2). The fortress holds significant historical importance due to its strategic location at the crossroads of various overland routes, making it an important stopover. The building contains architectural and decorative elements that were not present before Islam, such as pointed arches, scalloped niches, superimposed arches, and intersecting vaults. This style of construction became prevalent during the late Umayyad and early Abbasid periods. The fortress was built in the second half of the second century AH to serve as a governor's residence, as indicated by its layout, which resembles the design of the governor's residence in Kufa, featuring living quarters, administrative facilities, and courts. Moreover, the Ataabi fortress was constructed on the ruins of earlier structures, enhancing its historical value [18]. The Al-Ukhaidir complex includes various facilities, such as the fortress, palace, and their annexes. The fortress itself is a rectangular structure built with stones, bricks, and plaster. Some of the facilities are located inside the fortress, while others are outside. The fortress measures 175 meters from north to south, 169 meters from east to west, and stands 21 meters high. The external wall and gates serve as points of connection between the exterior and interior spaces. These include:The Wall

The wall is a robust fortification surrounding the palace from all directions, reinforced with towers. Between each tower are two semi-circular arches with openings used for lighting, ventilation, and defensive purposes. The inner facade of the wall is decorated with arches similar to those on the outside, but not symmetrical. Each corner of the wall's interior has a staircase leading to the upper passageway. The northern wall is in better condition than the others and differs from the rest as it is adjacent to the palace on the inside. The exterior of the northern wall is adorned with small niches with arches resembling a horseshoe shape, supported by small columns [19,20]

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The Gateways in the Wall

Each side of the wall features a central gate, all similar except for the northern gate, which differs due to its rectangular towers. All gates lead to the open courtyard, except the northern one, which provides access to the palace interior. The main gate is situated on the northern side of the wall, flanked by large rectangular towers. It opens to a covered passageway with small dark rooms on either side, leading to a rectangular courtyard with a distinct domed ceiling featuring an internal segmented design. On either side of the courtyard is a corridor separating the wall from the palace[20]). The wall also includes defensive recesses where arches meet the wall, allowing hot oil to be poured on attackers through a 22 cm wide opening from the defensive passage above the wall. This feature is considered the first of its kind in military architecture. A covered defensive passage runs along the top of the wall, accessible by stairs at the corners and gate entrances. Another military element is the sliding gate, or "zalaqa," which became common in Arab and Frankish forts, lowered from above using ropes and pulleys. It includes a guard room (darakah) equipped with drop slots for attacking intruders (Figure 2)

Figure 2 The outer wall and surrounding towers, along with the northern wall and main entrance of the fort. (Al-Naqeeb,

Key Architectural Elements in Al-Ukhaidir Fortress

The architectural elements of Al-Ukhaidir Fortress are diverse, with features such as the pointed arch, which was extensively used in the construction of entrances, niches, and vaults, serving both aesthetic and structural purposes.

The Muslim architect skillfully addressed the intersection of vaults at the corners with a unique approach. Additionally, there was a proficient use of vertical and horizontal loopholes, as well as sliding doors, which were well-suited to the fortress's defensive function. The architects also excelled in the creative use of brick and gypsum, arranging them in various patterns to form artistic panels[21].

Islamic architecture. Additionally, the palace includes corner niches, located beside the prayer hall vault. These niches are significant architectural elements within the palace, later playing a crucial role in dome construction by transforming a square hall into a shape closer to a circle, suitable for supporting a dome[22].

Among these decorations is the "woven mat" design, which is considered the oldest surviving example of its kind in Islamic architecture. An important architectural feature of this palace is the "bustak," a unique element in Arab Islamic architecture characterized by a semi-cylindrical vault that rises above parts of the building. This is regarded as the oldest example of its kind in Arab Islamic architecture. Additionally, the palace includes corner niches, located beside the prayer hall vault. These niches are significant architectural elements within the palace, later playing a crucial role in dome construction by transforming a square hall into a shape closer to a circle, suitable for supporting a dome(**Table 1**)(Figure 3)[22].

Figure 3 Shows the main entrance of Al-Ukhaidir Palace

Table 1 Descriptive Analysis of Variables Related to Al-Ukhaidir Fortress

Aspect	Transformation Element	Analysis
Transformation at the Whole Level	Resulting Morphological Changes	Emergence of pointed arches, shell niches, overlapping vaults, and intersecting vaults that were not present before
	Description of Outer Boundaries of the Shape (Shape Unit)	There is a shape unit through gradation
	Diversity in Formation	Each side of the fortress wall has a gate in its middle, similar except for the northern one, which is different because its towers are rectangular
	Methods of Formation (Regular Transformations, Irregular Transformations)	The inner facade of the wall is adorned with arches similar to those on the outside but not symmetrical
	Compatibility with Functional and Contextual Determinants and Achieving Symbolic Requirements	Includes a defensive fortress, palace, residential facilities, administration, and diwans
	Continuity in the System	There is clear continuity through the wall supported by towers and semicircular arches that penetrate these arches were used for lighting, ventilation, and defensive purposes
Transformation at the Part Level	Height of Facades	The main entrance facade is higher than the rest of the wall, and there are recesses in the wall for defensive purposes
	Proportions of Openings	There are differences in the proportions of openings, recesses in the wall for defensive purposes, and small openings for rooms and dark areas
	Shapes of Openings	Openings are in the form of two semicircular arches or small rectangular ones for defensive purposes
	Continuity of Facades	The facades are continuous with defensive towers and recesses
	Visual and Symbolic Value	Appearance of artworks, including mat decoration
Mechanisms of Transformation	Qualitative Continuity (Selection of Visual and Spatial Mediums)	Through the phenomenon of (Bishtak), where the space is in the form of a half-cylindrical vault and rises above parts of the building
Mechanisms of Transformation	Spatiotemporal Continuity (Change of Place Over Time with Continuous Movement)	Built on the ruins of previously existing buildings

	Stages of Transformation (Modification, Rearrangement, Reassembly)	There are no stages because the buildings before it were dilapidated
	Transformation (Continuous Time with One Shape, Discontinuous Time with Multiple Shapes)	Continuous time using semicircular arches

The Mustansiriya School in Baghdad

The Mustansiriya School is considered one of the enduring architectural masterpieces of Baghdad, showcasing the architectural excellence of Iraq in the field of Islamic educational buildings. It was inaugurated in 631 AH (1233 AD) and was constructed on a large area, with a length of 104.8 meters and a width ranging from 48.8 meters in the south to 44.2 meters in the north. The overall plan of the Mustansiriya School is rectangular, with the southern side extending 4.6 meters beyond the northern side. A prominent entrance protrudes in the middle of the northeastern side. A large central rectangular courtyard occupies more than one-third of the total area, surrounded by spaces on all sides[23–26].

Spatial Organization

From studying the plans of the Mustansiriya School building, it is observed that the spatial organization adopted is a centralized pattern, where the central courtyard serves as the focal point. The mosque is positioned in the courtyard opposite the main entrance, flanked by two iwans (halls) on the northwest and southeast sides.

This arrangement allows the courtyard to be used as an additional space for prayer. Between the entrance, the iwans, and the mosque, there are repeating units consisting of small domed rooms, grouped into four distinct architectural clusters, each almost independent from the others. The study halls are located on the southeastern side, with doors opening onto a corridor leading to each. Service areas like storage rooms, kitchens, and baths are strategically placed at the corners and edges of the building[24,25].

Figure 4 Illustrates the entrance of the Mustansiriya School, the mosque's mihrab, and the decorative elements adorning the facades of the doors and iwans within the school

Components of the Mustansiriya School - The Main Entrance

The main entrance of the school is situated nearly in the middle of the northeastern side. It is a tall structure, rising up to 16 meters above the rest of the building, and protruding 3.5 meters outward from the wall. Inside the entrance is a vaulted space resembling an iwan, with a decorated ceiling leading to the courtyard of the school. The entrance is marked by a pointed arch resting on two cylindrical columns attached to the wall[25] (Figure 4).

The entrance's significance is highlighted by its size, construction style, and the decorative embellishments, featuring a façade surrounded by a rectangular frame with geometric shapes. Inside this frame are large pointed arches that crown the entrance, and beneath them is a pointed arch doorway. The wall surface between the large arches and the doorway is adorned with diverse decorations, surrounded by inscriptions indicating the name of the caliph who founded the school, its dedication to scholars of the four Sunni schools of thought, and the date of its establishment[24,27] .

The Central Courtyard (The Sahn)

The central courtyard is a large, open, rectangular space measuring 62.4 meters in length and 27.4 meters in width, with a total area of 1,710 square meters, exceeding one-third of the school's total area. The courtyard is surrounded by the school's spaces on all sides, with decorated façades featuring pointed arches. This courtyard serves as the primary source of light and air for the rest of the school, with all door openings facing this central space. The courtyard also included a pond in its center, supplied with water from the Tigris River via a conduit beneath the school's terrace to provide drinking and washing water[28][25,29].

The study halls

The study halls are situated in the southeastern section of the building. The school features seven large halls, each with a height of two stories. These halls have entrances that open onto a corridor measuring 34.6 meters in length and 1.4 meters in width, which is connected to the school's courtyard by two passageways—one on the right side and the other on the left side of the southern iwan. The corridor's ceiling is elevated, reaching a height of 9 meters, and is designed in the shape of a pointed vault with four evenly spaced openings. The halls vary in size and shape, with their ceilings incorporating upper openings to allow light and air to enter (Figure 5) [24,29].

Figure 5 Architectural and decorative elements of the Mustansiriya School in Baghdad. . (Mustansiriyah Madrasah (2025) - All You Need to Know BEFORE You Go (with Reviews), n.d.)

The Mesnat

The "Mesnat" is a retaining wall that forms a walkway running along the Tigris River adjacent to the Mustansiriya School. Constructed from brick, this passageway or road was built due to the proximity of the building to the river, allowing people to pass through this significant location. This proximity also necessitated special attention to the school's façade facing the river, particularly in terms of its decorative The Iwans

The Mustansiriya School contains three iwans; two of them are within the building overlooking the courtyard. The first is connected to the main entrance, with a vaulted and decorated ceiling and a large, pointed arch opening to the courtyard, supported by two cylindrical brick columns attached to the wall. The other two iwans are located on the northwest and southeast sides, opposite each other and similar in general shape. Each forms a large hall open on one side with a vaulted, decorated ceiling about 9 meters high, and their façades facing the courtyard rise above the rest of the building[29].

The Mosque

The mosque is located on the southwestern side and is a regular rectangle measuring 23 by 5.9 meters, with its long side parallel to the qibla wall. It faces the entrance and opens onto the courtyard, featuring a prominent mihrab (prayer niche)(Figure 4). The strategic placement of the mosque allows for the courtyard to be utilized when the prayer hall becomes crowded during special occasions. The architectural design of the mosque's façade facing the courtyard includes entrances with a central arch flanked by two symmetrical arches[24,27,29].

Elements and commemorative inscriptions that adorn it [24,29](Figure 6).

Figure 6 depicts the windows, calligraphic decorations, woven patterns, and cut arches that adorn the façade of the school overlooking the Tigris River

The Facade

The facades of the Mustansiriya School are distinguished by their use of proportional relationships and modular units, featuring a grid division with dimensions of 10-30 Byzantine cubits (1 Byzantine cubit = 31.23 cm).

This technique represented a technological advancement for its time and remained in use for the following seven centuries across the Islamic world. Additionally, these facades are notable for their unique decorative treatments, which clearly indicate the extent of progress and development in the field of decorative arts during that historical period. This is evident in both the methods of production and the nature of the decorative forms themselves[24].

Regarding the methods of creating the decorations, several techniques were employed: variations in the positions of the brickwork itself, carving and cutting the bricks into different shapes and sizes according to a precise geometric plan to create the desired decorative pattern, as well as engraving designs on the bricks to create a contrast between light and shadow, enhancing the clarity and dimensionality of the decorative elements. As for the nature of the decorative forms used, a variety of geometric shapes are observed, often comprising a decorative unit that frequently resembles star-shaped patterns capable of being repeated from four directions. The vegetal decorative elements are typically found within the spaces of the geometric shapes and are also seen beneath commemorative inscriptions and between the letters. These elements are characterized by their symmetrical forms, opposing and interlocking units, crafted in an exquisitely beautiful manner (Figure 7).

Figure 7 Illustrates various types of decorations, such as star-shaped and mat-shaped patterns, as well as commemorative inscriptions

It is noteworthy that these decorations, in their various forms, are made from pieces of fired brick. In terms of the arches used in the facades of the Mustansiriya School, there was a focus on the pointed arch, which is considered a distinctive structural and decorative feature in Islamic architecture. This element was employed in various sizes, shapes, and forming methods. For instance, within the openings of the rooms overlooking the courtyard, the arch was used in a size suitable for a room entrance, followed by a larger size for the openings of the upper arcade overlooking the courtyard, and an even larger size for the mosque entrances also facing the courtyard. The largest arch size was observed in the central entrance, followed by an even larger one within the openings of the iwans. Additionally, the use of gradation and repetition of this arch within some facades contributed to a sense

of unity in the overall design of the Mustansiriya School facades, enhancing their architectural harmony (Figure 7)(**Table 2**) [30].

Table 2 presents the descriptive analysis of the variables related to Al-Mustansiriya School.**Aspect**	**Transformation Element**	**Analysis**
Transformation at the Whole Level	Morphological Transformations Resulting from	Inside the school, there is an iwan with a decorated vaulted ceiling designed in a pointed arch, overlooking the school's courtyard through a vaulted arch supported by two cylindrical columns attached to the wall.
	Description of the External Boundaries of the Shape (Formal Unit)	The use of gradation and repetition added a sense of unity to the facades. The exterior facade is plain and devoid of details, while the facade facing the Tigris River features windows, inscriptions, woven decorations, and cusped arches. The interior facade includes the main entrance iwan and the facade of the mosque within the school.
	Diversity in Forming	The school contains three iwans: the main one has a decorated vaulted ceiling with a pointed arch, while the other two are opposite each other and similar in shape, each featuring a large hall open on one side with a decorated vaulted ceiling approximately 9 meters high. The arrangement of the brick units varies, either by different placement or through carving and cutting into various shapes and sizes. Irregular transformations are present in the structure, such as the varying height of the entrance compared to other parts.
	Forming Methods (Regular Transformations, Irregular Transformations)	Between the entrance, the two iwans, and the mosque, there is a repeating unit consisting of a small domed room that forms architectural clusters.
	Compatibility with Functional and Contextual Constraints and Meeting Symbolic Requirements	This school was established with a specialization in studying Islamic jurisprudence according to the four schools of thought and contains a mosque and classrooms. Service activities, such as storage rooms, kitchens, and bathrooms, were located in specific corners and niches.
	Continuity in the System	The facades of Al-Mustansiriya School are distinguished by the use of proportional relationships and modular units.
Transformation at the Part Level	Facade Height	The entrance rises significantly above the rest of the building, reaching a height of 16 meters, and it projects outward from the wall by 3.5 meters. It is noticeable that the iwans are taller than the rooms on the upper floor. The classrooms have upper openings in their ceilings to allow light and air to enter and are connected to the iwan through two corridors—one to the right of the southern iwan and the other to the left—with a high vaulted ceiling containing four evenly spaced openings.
	Proportions of Openings	The surface of the wall between the large arches and the door opening is adorned with a variety of decorations surrounding commemorative inscriptions.
	Shapes of Openings	The architectural composition of the mosque's facade overlooking the courtyard includes entrances in the form of a central arch flanked by two symmetrical arches. The brickwork carvings create a contrast between light and shadow, enhancing the clarity and three-dimensional effect of the decorative elements.

	Continuity of Facades	The facades of the school are distinguished by unique decorative treatments, with the iwan featuring decorated and ornamented facades using pointed arches.
	Visual and Symbolic Value	A central pattern is evident, with the central courtyard as the focal point of the organization.
Mechanisms of Transformation	Qualitative Continuity (Selection of Visual and Spatial Media)	The school was built alongside the Tigris River next to the Caliphate Palace.
	Spatiotemporal Continuity (Change of Place Over Time with Continuous Movement)	Symmetrical and interwoven elements were used in a beautiful and aesthetically pleasing manner.
	Stages of Transformation (Modification, Rearrangement, Regrouping)	The elements featured repeatable star-shaped decorations on all four sides, while the plant motifs were set within spaces and geometric shapes. Commemorative inscriptions appeared, showing rearrangement and regrouping.
	Transformation (Extended Time with One Form, Interrupted Time with Multiple Forms)	The interrupted time using the tapered node shape has been utilized with various sizes and forms, employing different shaping methods.

Louvre Abu Dhabi Museum

It is one of the most important architectural projects in the world, and is a distinctive cultural platform that combines art, culture, and architecture. It was designed to be a global museum that reflects the heritage of humanity and promotes cultural exchange between the East and the West. The Louvre Abu Dhabi Museum is located on Saadiyat Island in Abu Dhabi, United Arab Emirates. The museum was designed by architect Jean Nouvel, and is one of the finest examples of the use of modern materials in an architectural design inspired by elements of Islamic culture. Aluminum and reinforced fiberglass were used as part of the main structure, with an emphasis on the interaction of light and shadow, which is a distinctive feature of Islamic architecture (Figure 8) [31]. The most important architectural elements:

The huge interlocking dome

This dome was designed using a network of metal panels reinforced with fiberglass, an innovative design that reflects the Islamic influences in the use of domes. The dome is not just a traditional architectural element, but rather an interactive structure where the metal panels in a complex geometric pattern create amazing light and shadow effects on the interior spaces. The dome reflects a transformation from the traditional design of domes in Islamic architecture to a contemporary form that enhances aesthetics and functionality at the same time (Figure 9) [32,33].

Figure 9 Image 1. Louvre Abu Dhabi Museum: Interior view (Litova, 2020)

Metal grid and architecture

The metal grid was used, which was designed in the form of an electric current similar to traditional conventional currents, but using modern materials such as aluminum and fiberglass. This grid contributes to forming the traditional structure of domes, as the domes are replaced by a solid fiber grid and a natural optical grid by entering in a way. Here it turns to using multiple grids of many elements, making it more dynamically interactive between light and shadow. [32].

Use of Natural Light

Natural light has been used in an innovative way to distribute it in the interior spaces through cracks and metal grids, which creates moving light effects throughout the day. The museum reflects traditional Islamic architectural techniques in the use of light and shadow, but with modern techniques and innovative materials. Light enters through the openings and grids in ways similar to the traditional methods used in mashrabiyas or Islamic arches, but in a contemporary and energy-efficient way [34].

Shift in the use of materials

The biggest shift in the architectural form of the museum is the use of modern materials such as fiberglass reinforced plastic and aluminum instead of traditional materials such as stone or wood. These modern materials provide design flexibility and high structural strength while reducing weight.

The shift here is embodied in the use of light and strong materials that enable the construction of complex architectural structures that would have been difficult or impossible using traditional materials. [34].

Interaction between interior and exterior

In Louvre Abu Dhabi, the interior and exterior interact in a unique way. The design allows for a harmony between the open interior spaces and the exterior spaces located near the sea. The interior spaces are characterized by their large size and open space that reflects traditional Islamic architecture in terms of volume, but they are designed using modern materials and innovative design techniques. This formal transformation is evident in the design of the corridors and public spaces that allow movement and light to flow smoothly between the interior and exterior.[32].

Transformations in the use of facades.

The facades in the museum differ from traditional buildings, as they are characterized by the presence of complex geometric details[35], but at the same time they represent modernity in architecture. We can see how glass and metal elements were used to present a contemporary design while preserving the traditional spirit of Islamic buildings. This transformation reflects how fine decorative details can be combined with modern technologies to produce facades that are both attractive and functional (**Table 3**) [34].

Table 3 presents the descriptive analysis of the variables related to Louvre Abu Dhabi Museum

Aspect	Transformation Element	Analysis
Transformation at the Whole Level	Morphological Transformations Resulting from	The dome appears as a network of metal panels reinforced with fiberglass.
	Description of the External Boundaries of the Shape (Formal Unit)	The unity of form is majestic.
	Diversity in Forming	Diversity in engineering formation, materials and techniques used
	Forming Methods (Regular Transformations, Irregular Transformations)	Geometric formation - network - optical and layered
	Compatibility with Functional and Contextual Constraints and Meeting Symbolic Requirements	It contains the optimal spaces for exhibitions and facilitates the movement of visitors, in addition to being compatible with the surrounding cultural context that includes spirituality, architectural heritage and symbolism through the use of materials, geometric shapes and changing atmospheres to create an

		environment that interacts with visitors on multiple levels, whether functionally, culturally or symbolically.
	Continuity in the System	Integration of geometric shapes and modern materials
Transformation at the Part Level	Facade Height	The height of the facade changes gradually depending on the internal spaces that are distributed.
	Proportions of Openings	The proportions of the openings vary in size and shape throughout the building, reflecting an interaction between function and beauty. The shifts in the proportions of the openings are not just a design element, but also relate to the control of light and ventilation, and the interaction with the surrounding environment.
	Shapes of Openings	Various opening shapes are used, ranging from circular to rectangular and square openings, to overlapping or decorative openings. These various shapes are used in an integrated manner within the building to generate various light and ventilation effects in the different spaces.
	Continuity of Facades	The continuity of the facades is achieved by creating a flexible system of openings and grids that transform the incoming light into changing patterns of light and shadow. This transformation ensures that visitors move between the interior and exterior areas without experiencing sudden or sharp changes in lighting.
	Visual and Symbolic Value	It is central to creating a rich spatial experience that is not limited to admiring visual beauty alone, but extends to the symbolic experience that relates to culture, space, time, and humanity. The building combines spiritual symbolism with architectural aesthetics, making it not just a place to display art, but also a place to contemplate and interact with the world around it.
Mechanisms of Transformation	Qualitative Continuity (Selection of Visual and Spatial Media)	Through the harmony between spaces, the manipulation of shadow and light, and the use of natural materials.
	Spatiotemporal Continuity (Change of Place Over Time with Continuous Movement)	Built on Saadiyat Island
	Stages of Transformation (Modification, Rearrangement, Regrouping)	There are no stages.
	Transformation (Extended Time with One Form, Interrupted Time with Multiple Forms)	Extended time using geometric patterns of different sizes and shapes and in different formative ways

Analytical Methodology

The study adopted a combined descriptive–quantitative analytical approach to examine the theoretical framework of formal transformations across three selected case studies, each representing a distinct temporal and functional shift:

1. Al-Ukhaidir Fortress – Karbala (Early Abbasid Era)
2. Al-Mustansiriya School – Baghdad (Late Abbasid Era)
3. Louvre Museum – Abu Dhabi (Contemporary architecture inspired by Islamic aesthetics)

Each case was systematically analyzed using a set of core architectural geometric indicators, enabling a quantitative assessment of formal transformation patterns across different historical and cultural contexts.

1. Openings to Block Ratio (O/B Ratio)

Formula: O/B Ratio = (Total Opening Area / Total Block or Wall Area) × 100

Total Opening Area: The cumulative area of all architectural openings (windows, doors, arches, etc.).

Total Block Area: The entire area of the façade or architectural mass.

Used to evaluate façade openness versus solidity.[36]

2. Index (RI)

Formula: RI = Number of Repeated Elements / Total Number of Elements

N_repeated: Number of repeated architectural elements (windows, arches, ornaments, etc.).

N_total: Total number of design elements on the façade.

Measures the degree of formal repetition in architectural composition.[37]

3. Vertical Gradient Index (VGI)

Formula: VGI = (H_max - H_min) / H_avg

H_max: The highest architectural point on the façade.

H_min: The lowest architectural point.

H_avg: The average height of façade elements.

Assesses vertical distribution of mass in architectural form.[38]

4. Natural Daylight Efficiency Level (NDLE)

Formula: NDLE = (n × T × A) / (V × D)

n: Number of daylighting apertures (windows, skylights, etc.).

T: Glass transmittance (the transparency rate of the material).

A: Total aperture area.

V: Total internal space volume.

D: Depth from the window to the farthest interior point.

Quantifies natural daylight efficiency inside spatial environments.[39]

Quantitative Analysis

First Case Al-Ukhaidir Fortress

This section presents the quantitative analysis of the first case study: Al-Ukhaidir Fortress, located in Karbala, dating back to the early Abbasid era. The analysis is based on four architectural performance indicators derived from measured visual data and architectural drawings.

Openings to Block Ratio (O/B Ratio)

Formula: O/B = (56 / 683) × 100 ≈ 8.2%

Interpretation: The façade features very limited and small openings (≈8.2%), primarily designed for defense rather than light or ventilation. As shown in Figures 2 and 3 of the study, these openings are restricted to narrow arched slits and elevated air vents, clearly reflecting the building's fortified and closed massing strategy.

Repetition Index (RI)

Formula: RI = 31 / 50 ≈ 0.62

Interpretation: The repetition of architectural elements such as towers and semicircular arches is partial and irregular. Although arches recur between towers, their distribution lacks clear symmetry, resulting in a moderate RI value (0.62), which suggests controlled yet non-uniform design.

Vertical Gradient Index (VGI)

Formula: VGI = (9 - 4) / 6.1 ≈ 0.82 → Approx. vertical difference = 1.3 m

Interpretation: The difference in height between the central gate and the surrounding walls is limited (around 1.3 meters). This includes elevated features like bastions and corner towers. The architectural composition remains horizontally aligned with minimal vertical variation, emphasizing defensive uniformity.

Natural Daylight Efficiency Level (NDLE)

Formula: NDLE = (4 × 0.35 × 1.8) / (180 × 2.1) ≈ 0.035

Interpretation: The extremely low daylight efficiency (≈0.035) reflects the fortress's enclosed spatial organization, relying solely on narrow defensive openings for light access. Most rooms are dark, with thick walls and limited ceiling height. The design evidently prioritizes fortification over environmental comfort or daylighting.

In conclusion, the architectural geometry of Al-Ukhaidir Fortress demonstrates a highly defensive logic. The low O/B ratio, moderate repetition index, limited vertical hierarchy, and poor daylight distribution all reinforce the typology of a compact, protective structure optimized for security rather than spatial openness or visual comfort.

Second Case: Al-Mustansiriya School – Baghdad

This Abbasid-era educational and religious complex reflects a highly organized and environmentally responsive design. The analysis utilizes the same set of indicators as applied to Al-Ukhaidir.

Openings to Block Ratio (O/B Ratio)

Formula: O/B = (142 / 660) × 100 ≈ 21.5%

Interpretation: The openings-to-block ratio (≈21.5%) indicates balanced massing with a diverse set of openings including pointed arches, entryways, clerestory windows, and a large central courtyard. As illustrated in Figures 4 to 7, these features enhance both ventilation and light diffusion, especially along the river-facing façade.

Repetition Index (RI)

Formula: RI = 42 / 50 = 0.84

Interpretation: The architectural composition demonstrates a clear pattern of pointed arches and repetitive brick ornamentation. This regularity results in a high RI value (0.84), indicating a well-structured decorative and spatial rhythm aligned with Islamic architectural identity.

Vertical Gradient Index (VGI)

Formula: VGI = (14 - 3.5) / 7.8 ≈ 1.35 → Vertical variation ≈ 4.2 m

Interpretation: The difference in height between the monumental entrance and internal courtyard reaches approximately 4.2 meters. The design strategically employs vertical hierarchy to emphasize spatial importance, particularly in iwans and vaulted corridors.

Natural Daylight Efficiency Level (NDLE)

Formula: NDLE = (10 × 0.52 × 3.1) / (230 × 2.4) ≈ 0.68

Interpretation: The daylight distribution is relatively efficient (≈0.68) due to the use of open courtyards and clerestory elements. Light penetrates deeply into surrounding rooms, though some deeper chambers still experience moderate illumination levels.

Third Case: Louvre Abu Dhabi–Abu Dhabi

A contemporary architectural landmark inspired by Islamic geometry, this structure combines advanced materials and environmental design strategies. The quantitative assessment captures its high-performance daylighting and formal innovation.

Openings to Block Ratio (O/B Ratio)

Formula: O/B = (365 / 966) × 100 ≈ 37.8%

Interpretation: With an O/B ratio of ≈37.8%, the building exhibits a high degree of permeability. The dome's perforated surface, open latticework, and fragmented walls allow controlled daylight to penetrate deeply into the interior spaces, achieving expressive spatial openness.

Repetition Index (RI)

Formula: RI = 62 / 80 = 0.78

Interpretation: Although realized through modern materials, the repetition pattern in the metallic dome structure draws direct inspiration from Islamic geometric motifs. The RI value (0.78) reflects organized but flexible repetition, emphasizing a modern reinterpretation of historical principles.

Vertical Gradient Index (VGI)

Formula: VGI = (21 - 5) / 9.3 ≈ 1.72 → Vertical variation ≈ 6.5 m

Interpretation: The difference in height between the exhibition halls and the overhead dome creates a strong vertical contrast (≈6.5 meters). This variation contributes to a spatial drama and functional layering throughout the museum experience.

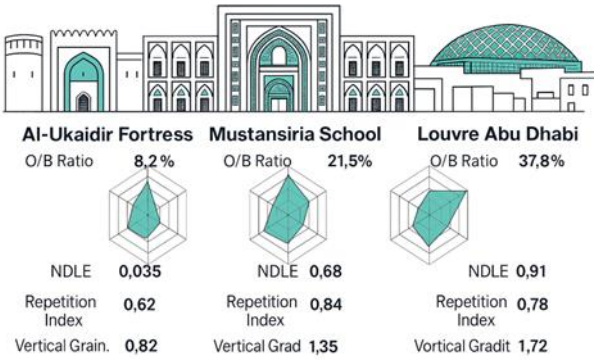
Natural Daylight Efficiency Level (NDLE)

Formula: NDLE = (34 × 0.89 × 4.6) / (590 × 2.3) ≈ 0.91

Interpretation: The Louvre achieves the highest daylight performance score (≈0.91), enabled by its engineered dome and complex aperture design. The result is a well-lit environment that balances thermal comfort and daylight autonomy. (Figure 10)(Table 4)

Table 4: presents the values derived from the applied study and quantitative analysis of the three project

the indicator	**Akhizar Fortress**	**al-Mustansiriya school**	**Al Lufr Museum**	**analysis**
O/B (%)	*8.2*	*21.5*	*37.8*	*The openness radiates*
RI	*0.62*	*0.84*	*0.78*	*The highest repetition of the Mastansariyyah*
VGI	*0.82*	*1.35*	*1.72*	*Ascending vertical gradient*
NDLE	*0.035*	*0.68*	*0.91*	*The most powerful natural lighting in Loofer*



Conclusions

1. Al-Ukhaidir Fortress and Al-Mustansiriya School exemplify distinct transformation mechanisms—Al-Ukhaidir displays symmetric structural diversity and defensive adaptations, while Al-Mustansiriya emphasizes verticality, central courtyards, and intricate decorative organization.
2. The organization and morphology of both buildings respond directly to contextual and functional determinants (defense and residence in Al-Ukhaidir; education and assembly in Al-Mustansiriya) demonstrating the adaptability of Islamic architecture to varied purposes.
3. The design, size, and arrangement of apertures and facades reflect changing needs for light, ventilation, defense, and symbolic, with each case study offering distinctive methods.
4. Decorative and symbolic aspects, such as geometric motifs and elaborate star patterns, enhance the visual identity and cultural significance of Islamic architecture.
5. Islamic architectural forms experience both regular (relative) and irregular (disproportionate) alterations, integrating traditional elements with contemporary solutions to address new practical and aesthetic requirements.
6. Traditional Islamic architecture preserves continuity using gradient, repetition, and modularity, yielding stable shapes and a unified visual character.
7. Architectural change is driven by adaptive reuse, spatial reorganization, and the integration of contemporary materials and technologies, as seen in both historic edifices and the Louvre Abu Dhabi.
8. The Louvre Abu Dhabi museum illustrates a modern reinterpretation of Islamic architectural principles, merging tradition with innovation through advanced structural solutions, dynamic light interplay, and the use of modern materials, reaffirming the relevance of Islamic heritage in global contemporary architecture.
9. Traditional models (Al-Ukhaidir Palace and Al-Mustansiriya School) relied on gradualism and repetition within the confines of the environment and traditional materials. Modern models (the Louvre Museum) expanded the scope of transformation using lightweight materials and interactive techniques.Increasing NDLE and Openings Ratio are directly linked to the trend toward contemporary architectural sustainability.

Recommendations

1. Conduct comprehensive and precise studies of buildings from the Abbasid era by delving into the minute details of various buildings, their influences, and the methods of morphological transformations applied to them.
2. Applying the approach of morphological transformations in local architecture is essential today to restore it to its proper path, especially after the emergence of strange designs and details in local architecture.
3. Increase cultural awareness among designers about the importance of studying morphological transformations in Islamic architecture through training courses and workshops.

4. Form transformations based on reinforced plastic and composite materials provide a contemporary extension of Islamic architecture, where modern materials contribute to representing the aesthetic and functional values that were the essence of the designs. This harmony between heritage preservation and innovation enhances the connection between different eras, creating a bridge that crosses architecture from the past to the future.
5. Researchers recommend the use of advanced software and computer modeling techniques to study morphological transformations that allow accurate mathematical patterns to be observed and compared over a long period of time, giving quantitative results that support the traditional qualitative analysis of Islamic architecture.
6. A framework should be developed that allows the principles of gradient, geometric repetition, and light and ventilation control patterns to be used in modern building designs, with guidance for designers on how to integrate these principles with green building requirements and internationally recognized environmental standards.
7. To maintain a comparable and analytical scientific database that supports academic studies and the restoration or simulation of Islamic patterns in new projects, thorough documentation using photography, 3D scanning, and precise architectural drawing is crucial.
8. To better understand the connections between morphology, societal change, and technological advancement in Islamic contexts, researchers advise that future studies involve interdisciplinary teams of scholars from the fields of sociology, history, and materials sciences in addition to architects.

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