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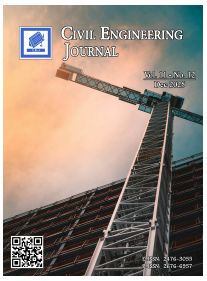

Assessing Urban Characteristics: The C-DNA As a Catalyst of Urban Morphogenesis

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Abstract

Historic city centers are cultural archives where built forms and spatial practices hold the collective memory of generations. In Baghdad, the concept of Cultural DNA (C-DNA) is a tool to understand how cultural codes are the generative rules that shape the evolution and persistence of the historic urban fabric. This research explores the role of C-DNA as a trigger of urban morphogenesis in Rusafa, the historic heart of Baghdad, by looking into how cultural values underpin spatial continuity, change, and adaptability. The study uses Space Syntax methodologies with DepthmapX, supported by historical maps, surveys, and field observations, to analyze two morphological stages of Rusafa: 1850 and now. Through axial analysis, the research measures integration, connectivity, choice, and control to evaluate key urban characteristics: centrality, hierarchy, privacy, and territoriality. This comparative approach highlights both continuity and disruption in the historic fabric. The results show that cultural nuclei (mosques, markets, khans, and schools) are still the central points of the city, anchoring movement and interaction across centuries. Despite the disruption caused by modern interventions like Al-Rashid Street, the organic urban fabric still holds the capacity to sustain privacy, territoriality, and hierarchical spatial arrangements. The findings prove C-DNA is not a metaphor but an operational system that generates urban order and resilience. The study concludes that understanding C-DNA is crucial for developing sustainable revitalization strategies in Baghdad and similar Islamic historic cities. By treating culture as the city's genetic code, planners and policymakers can design interventions that preserve cultural identity while accommodating urban needs.

Keywords: Cultural DNA; Urban Morphogenesis; Organic Urban Type; Centrality; Hierarchy; Territoriality.

1. Introduction

Culture is knowledge, a system of collective values, and socially transmitted patterns of behavior and thinking that are shared among individuals and support communication and social interaction. Culture is a meaning or social organization that lies behind routines and behavior in daily life. It represents the comprehensive system of inherited concepts, as they are expressed in symbolic forms, through which people communicate. Culture maintains and develops people's knowledge and attitudes towards life. It is similar to DNA in living organisms. DNA is a basic term in biology that is used to understand modern genetics. DNA is defined as the genetic material in the cell, and one of its major capabilities is the ability to store genetic information, transfer it, and express it in the characteristics of the same organism or outside of it. This is done by making copies of DNA transmitted during reproduction from one generation to another, as it forms a pattern for repeating the sequence of rules and relationships. This is a basic property of DNA because every new cell needs an exact copy of the old cell's DNA [1, 2].

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Historical centers can be interpreted from a tripartite perspective by being a repository of cultural resources (ideas, traditions, and beliefs); the framework that organizes the lives of its residents and their social experiences, which in turn creates social cohesion; and the interface linking them. It is represented by the cohesive urban fabric that creates a state of balance that is achieved in the urban system as a whole and appears in the form of a hierarchy in movement and urban activities, achieving the human scale through them, as well as creating a state of continuity in the urban environment [3].

The historical centers were distinguished by several common elements and qualitative and physical characteristics that succeeded in achieving a clear method or system for spatial formation. The hidden values, beliefs, concepts, and connotations that function as cultural codes and symbols were transformed into a visible physical structure characterized by special features linked to the nature of the place and the formation of its identity. C-DNA is the generator of a complex set of different layers of culture that appear over time in the form of physical elements. Understanding C-DNA makes it possible to understand the potential of the physical structure of historical centers and the reasons for their prosperity, transfer and circulate those potentials in the present and future, and find ways to restore life to them [2].

C-DNA is defined as an approach that focuses on place, people, and local development, where a place is built based on a deep understanding of local culture, social and economic resources, and community assets. By relying on C-DNA, it is possible to obtain better knowledge and understanding of the needs of the community and the way the place functions, unique resources, values, aesthetics, heritage, social interactions, and thus urban intervention under the distinctive origins of historical centers. Conventionally, the focus was primarily on the preservation of historical monuments, rather than generative cultural codes, which have a profound impact on shaping urban morphogenesis [4, 5].

Thus, C-DNA can be defined as a comprehensive approach that brings together several strategies and solutions. It is a method of experimenting with urban alternatives that provides a comprehensive approach to achieving the common goal, which is to understand the structure of historical centers, preserve them, and involve them in several scenarios aimed at transforming the structure of those centers into a flexible living structure. The goal of unveiling C-DNA is to deal with the urban problems and challenges of historical centers in a more culturally sensitive way, as C-DNA creates an architecture and urban scene that embodies the identity of the place, reflects the past, and looks to the future.

Urban morphogenesis, a term extracted from biological morphogenesis, describes the evaluation of the organism's form and structure, and it can be applied in a similar fundamental way to the urban structure, which undergoes continuous modifications influenced by internal and external catalysts. Urban morphogenesis refers to the formation, remodeling, modification, and adaptation of urban structures and changes in spatial types over time, influenced by cultural, social, environmental, and economic factors. The concept of urban morphogenesis examines the evaluation of the city's physical forms, spatial structures, and functional characteristics [6-8]. While many practices configure and shape the urban form, the most important factor in urban morphogenesis is cultural and social customary action, which refers to how residential life, work, and interaction, reflecting cultural values, influence the city's physical structure [9].

Previous research has highlighted this role. For example, Goodarzi et al. [10] described C-DNA as transferable geometric and functional patterns that explain the continuity of urban spaces. Nijkamp & Riganti [11] saw urban cultural heritage as the physical manifestation of identity, Tweed & Sutherland [12] how cultural environments embed meaning across generations [12]. Min & Lee [13] extended C-DNA to physical and virtual spaces. Marcos [14] and Netto et al. [15] linked urban morphogenesis to broader theoretical frameworks of geography, archaeology and morphology. However, few studies have systematically examined the role of C-DNA in urban morphogenesis—especially in Islamic historic cities like Baghdad.

Thus, the gap in the literature is how cultural values and traditions act as generative rules for centrality, hierarchy, privacy and territoriality in historic urban cores. To address this gap, this study uses Space Syntax and DepthmapX to investigate Baghdad's historic Rusafa district across two morphological stages (1850 and present) to see how C-DNA has influenced the persistence and transformation of urban characteristics.

The primary objectives of the study are:

- Examine the role of C-DNA in shaping the continuity and spatial organization of Baghdad's historic Rusafa center.
- Assess the influence of C-DNA on privacy, hierarchy, centrality, and territoriality by utilizing morphological analysis.
- Compare the morphology of both the contemporary and historical elements in order to expose the transformations impacted by C-DNA.
- Propose a framework which links sustainable revitalization approaches with cultural identity within historic centers.

2. Theoretical Formwork

Cities are living and dynamic scenarios that can reflect the cultural accumulations of their residents. Historical city centers can be considered storehouses of the cultural elements that appear in many forms in their structure. C-DNA tries to understand the urban structure by studying the comprehensive units and components and the relationships between them, revealing the cultures that make up the urban model, and then predicting the functional and formal pattern of the urban structure and how it will continue [16, 17]. The research focused on studying C-DNA and its impact on urban morphogenesis in the historical centers. Five basic characteristics were revealed in the construction of historical centers, which are based on the connection with cultural values (habits, practices, traditions, rites, and rituals), these are urban pattern, urban form, centralization, privacy, and hierarchy. The research's theoretical framework focuses on studying C-DNA and its impact on the urban characteristics or physical elements of historical centers.

2.1. Urban Type

Culture produces symbols, which form part of the general identity of society and establish a general pattern that organizes its symbols as hidden systems. The culture here includes a wide field extending from implicit social knowledge to explicit technical knowledge, with many interactions between them [18]. The term "C-DNA" refers to a mechanism for representing and transferring culture from one person or group of people to others (horizontal extension) or from one generation to another (vertical extension) [19].

C-DNA is born from geometric and typological representations influenced by functional and behavioral characteristics, and cultural and environmental sensitivity through man's endeavor to innovate ways to adapt to environmental conditions, and from life and the social systems surrounding him [20, 21]. Social systems are carriers of society's culture; thus, collective considerations are basic principles for urban organization. Cultural backgrounds enhance the sense of spatial belonging and social cohesion and create urban vitality, in addition to creating a unique identity through the spatial experience, which gives a sense of place [22]. The deep link between the cultural background and urban thought established and shaped the urban pattern, which is similar in appearance and has deep unity in its components, as well as giving residents a social and environmental behavior consistent with the city's physical pattern and form. For C-DNA to survive and continue, it must adapt to evolving and changing social values over time. The formation of the urban physical pattern and the changes that occur in it are due to the set of basic requirements of society and the specificity of the place and its system. These values together constitute C-DNA. This is similar to the function of genes in living organisms. The first models cannot be transmitted except through culture and socialization, which are genetically transmitted through genes from one generation to another within the scheme of evolution. Prototypes are environmental features that are repeatedly imitated and through which cultural actions and social customs are transmitted [13, 23].

C-DNA achieves the methods of reproduction, growth, and development of the urban type, which are the basis for representing and demonstrating the urban form, by specifying the requirements and conditions for producing the rules of the urban form. C-DNA represents the basic building blocks for representing the urban type, which is causally linked to the urban form. Urban classes develop over time to create or express their C-DNA and their communities, and thus cultural identity appears clearly in the urban pattern of historical centers. This is clear in the grid planning pattern of the city of Damascus during the era of the Roman Empire and its transformation into the organic pattern in the Islamic period, the wide streets of the classical style were settled and divided into additional facilities such as shops and houses. These streets turned into narrow, organic streets, and the agora (the square designated for markets and meetings) disappeared. Personal property was given importance in Islam, as homeowners could build and expand their property as long as they did not harm their neighbors. Therefore, organic, winding alleys were associated with Islamic cities, as property owners could expand their property without restrictions. In addition, livestock was the best means of transportation rather than vehicles, thus reducing the need for wide streets. These determinants and requirements that were associated with Islamic cities occurred slowly and took several centuries for the organic pattern to form [24, 25].

C-DNA has affected the dynamics of relationships between urban structural elements and units of historical centers, which has led to spatial and cultural transformations that are reflected in the urban morphogenesis through the language of urban and architectural patterns. These patterns result from human interventions based on environmental wisdom that has been developed over the years through trial and error, experience, and feedback. The generated urban form follows generative processes that create explicit and implicit relationships, proportions, and rules in the language of the urban form [26].

The organic pattern can be described as a biological system that reflects the human character and is not merely an agglomeration of physical structures. The organic pattern is considered the predecessor of all urban patterns. It consists of a basic unit or basic building block (a residential unit) and is usually assembled in a hierarchy and special networks, as it forms a complex and rich spatial arrangement with non-Euclidean geometry that achieves urban unification [26].

The growth of the organic pattern in terms of the visual and statistical systems is slow, similar to the growth of cells in living tissues, in harmony with the surrounding environment (cultural and environmental), and spontaneously (automatically). The organic pattern arises from a countless number of individual decisions that constitute the small basic structural units, and the urban fabric is the result of the relationship of these units with each other [27].

Cellular or local organic growth occurs through the successive addition or deletion of basic elements and thus creates a pattern appropriate to its context and environment. It is a system closer to the gradual accumulation of cells or units, which can be gradually replaced or renewed. The organic pattern adopts biological proportions that are in harmony with the human scale, it is a human pattern, not just a conglomeration of physical entities or structures. Growth occurs in the organic system, such as the growth of an organism from the bottom to the top, unlike the geometric system, which occurs from the top to the bottom. Its movement patterns and systems are similar to trees and spider webs [25].

2.2. Territoriality

The term territoriality can be understood in terms of privacy and personal space, and through it, a person can create different types of boundaries to organize interaction between himself and others in the urban environment [28]. Privacy is a concept with a spatial, cultural, and social dimension. Through C-DNA, privacy can be defined as a basic control feature in the self-permanence of urban physical organization. Privacy does not mean isolation; rather, it manages and organizes social interaction and preserves self-identity by clarifying the boundaries between the public and private spheres.

The private space in the historical centers acquires the utmost importance in the urban morphogenesis process. It is known as the base of the social and cultural structure, which guarantees the ideological and cultural stability of the entire spectrum of society. The interaction between the public and private spaces takes place through a series of hierarchical spaces with a hierarchy of privacy that works to organize the spatial spaces in the urban structure [2]. Transitional semi-private spaces, which are protected and subject to visual control and surveillance, are separate public and private places. In addition, the public and private spaces are separated in the historical centers by land uses, as the residential network for private use is separated from the commercial ones for public use, so commercial activities are located on the main axes leading to the center of that structure, while residential activity occupies the internal neighborhoods of private space and remain isolated from public movement [29, 30].

2.3. Centrality

Centrality is defined as the characteristic of a central place in its surroundings. In urban design, centrality refers to the notion of the existence of a focal point or space with a clear identity that occupies a prominent, central, and strategic location within cities [31, 32]. The center is a place that focuses on social interaction, cultural exchange, and economic activity, working to enhance the identity, vitality, and attractiveness of the urban structure and improving liveability and quality of life [33, 34].

C-DNA includes concepts with cultural and social extension, that show their profound impact in shaping the centre's physical structure, building architecture, and social dynamics. Thus, it is reflected in the differentiation of a center with dynamic characteristics (visual, structural, functional, and economic) that are dominant in the structure of the organic urban fabric [35].

The organic fabric of historic city centers arises from a physically clear and focused center that serves as a focal point for religious, social, and economic activities. They are not only physical centers but also centers of cultural exchange and community cohesion, which is the basis of the idea of centralization in historical centers [18, 22]. The organic fabric grows slowly around a clear center (the Grand Mosque, the shrines), and the growth occurs by radiating from the center towards the edges. In other words, the urban formation revolves around a clear and influential central focus, and from it radiate the axes of movement represented by a network of narrow and winding alleys leading to and from markets and residential neighborhoods. This confirms the importance of that central focus as a prominent landmark in the urban morphogenesis and life of the society, and affects its functional, structural, social, and cultural composition [36, 37]. The center occupies a clear role in organizing and structuring the dense urban fabric; it creates cohesion between the elements of the urban structure and preserves it from urban failure. It also forms a social space where people interact, share news, and exchange ideas [38, 39].

2.4. Urban System

A pattern language is distinctive from urban form language since it reflects the evolution of practical solutions over thousands of years, while urban form reflects geometric rules that combine visual perception and tectonic rules. Every urban structure is subject to organizational regulations similar to those to which a living organism is subjected to achieve adaptation to the surrounding environment and human requirements; therefore, every adaptive urban structure governed by a specific pattern is a product of human interaction, as the pattern is the basis for the formation of the urban form [40].

Cities grow and develop like living organisms through constant interaction and relationships with their surrounding environment. Organic cities are more operational, more efficient, and more equitable or equal in opportunities [41]. Urban morphogenesis and cellular growth through the successive deletion and addition of structural elements create an urban form, which is more appropriate to the context and its environment.

The urban form reveals the approach that reflects the culture of society and places through mass, space, and activities. The urban fabric is the final product (end product) of the process of interaction of constants such as cultural, environmental, and social factors with variables such as economic, urban, and industrial potential to reach the final product, which is the built environment [42]. The cohesive urban form of the historic fabric is the result of several stages and phases of social interaction with the tangible urban environment, which in turn reflects the lived experiences of previous generations, as that environment continues to support the contemporary communities that occupy it. In addition, the values inherent in spatial urban formations can represent the core cultural values capable of confronting emerging changes and maintaining the strength of the urban fabric of historical centers [43, 44].

The traditional fabric of historical centers with an organic form appears to be a chaotic, random fabric. However, it is a regular fabric with a complex shape, emerging from a clear and influential compositional nucleus, from which the urban fabric grew through irradiation outward. This nucleus dominates the dense urban fabric and strongly influences its functional, social, and cultural (religious) structure.

In addition, it can be observed that there are small urban structures with regular relationships that are repeated within the organic fabric, which in turn constitute a large percentage of the structure of the historical center. In their complexity, these structures constitute regular or similar spatial organizations that depend on a simple, specific, and regular geometric organization and arrangement. The organized complexity in urban form reflects a tool for generating ideas and shapes and developing them to be designs adapted to their environment, as complexity reflects the urban structure and the information stored in it. This appears in the form of relationships between parts of the structural system or the way the urban system works. The organic system also achieves the phenomenon of spatiality within the structure of the urban fabric in the historic center, which affects the density of social urban use and thus makes the city alive and safe. Urban compactness is an embodiment of social science methods that determine how urban spaces are formed, which enhances the comprehensive interconnection between spatially connected urban spaces that depend primarily on pedestrian movement to create a livable urban structure [45].

2.5. Hierarchy

Hierarchy is an organizational structure in which a group of independent and interconnected elements are arranged according to their level of importance in the system and the form of that system, thus forming a unified and integrated whole [46, 47]. In urban morphogenesis, the hierarchy is a natural organization of the urban structure that grows organically from the bottom to the top and consists of a hierarchical organization of the elements of the urban structure. This organization depends on the size and effectiveness of the buildings and the area of urban spaces. The rank of urban spaces' network has an inverse relationship to their number; the higher the rank of spaces, the smaller their number, and vice versa, the lower the rank of spaces, the greater their number. The elements of the urban structure, including urban spaces, are distributed hierarchically to achieve the purpose for which they were created. Events and activities are also distributed according to location, importance, and arrangement within the urban system [47, 48].

The natural hierarchy in the urban system in historical centers has been linked to cultural and social factors, as it is considered a main strategy for achieving security, privacy, and social interaction between residents using physical and non-physical elements that meet the needs of distinguishing between activities and users of the urban structure. This structure contains a hierarchical space that grades from public, semi-public, semi-private, and then private spaces. The beginning of hierarchy begins from the center of the urban environment, passes through the retail markets, and ends within the residential neighbourhoods, which are a network isolated from the public network to provide privacy for residents [48].

In the historic centers that have grown organically, the central area is a public urban space that includes the public mosque and an open space that forms the flexible public urban space that is used for religious celebrations as well as daily events and social interactions, which enhances the sense of justice and equality among people. As the bazaar, it takes a linear form that serves as the city's backbone and continues towards the main gates. As for the corridors or alleys, they are branches of the linear bazaar that connect the city center with the residential neighborhoods' centers, which are semi-public spaces. The center of the neighborhood leads through secondary alleys to open spaces, which constitute semi-private spaces in residential neighborhoods controlled by a group of residents. The privacy in these spaces is much higher than the rest of the urban spaces in the city's structure, which encourages social interaction between residents and enhances the management of privacy and the feeling of belonging, connection, and control over the place. The semi-private residential spaces are linked with private spaces through connectors, narrow blocked alleys, and then broken (forged) entrances. The repetition of closed branches, twists, and turns in the organic pattern makes it more defined and controlled by the occupants. The interstitial spaces and transitional spaces also make the structure of the historic center more spatially and functionally distinct, as they make the public and private areas separate and yet interconnected [49, 50]. Figure 1 shows the impact of the C-DNA on the urban morphogenesis in historical centers.

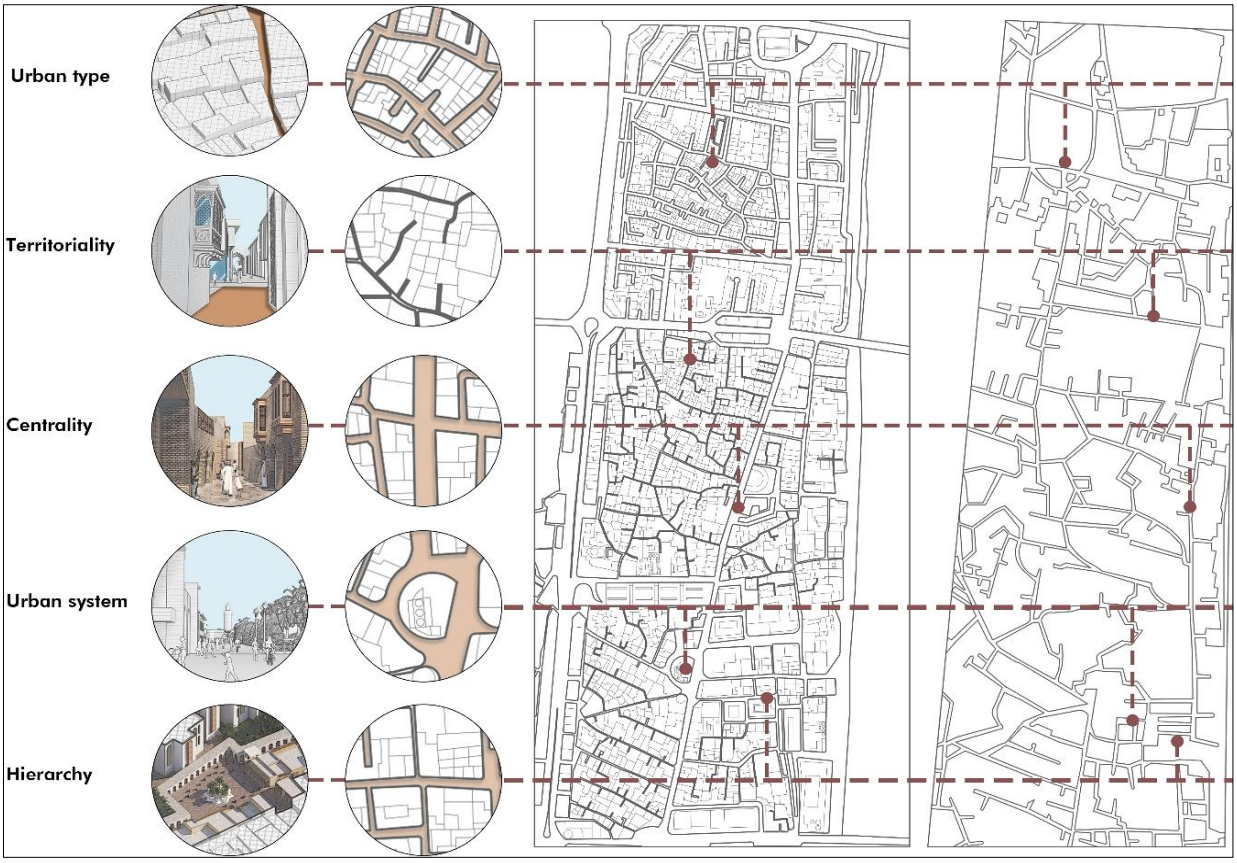


Figure 1. Shows the impact of C-DNA on the urban morphogenesis in the historical centers

3. Research Methodology

In this section, the paper will focus on testing the study area in two morphological stages to measure the impact of the C-DNA on the urban morphogenesis in historical centers, by forming urban characteristics, Figure 2 shows the research methodology diagram.

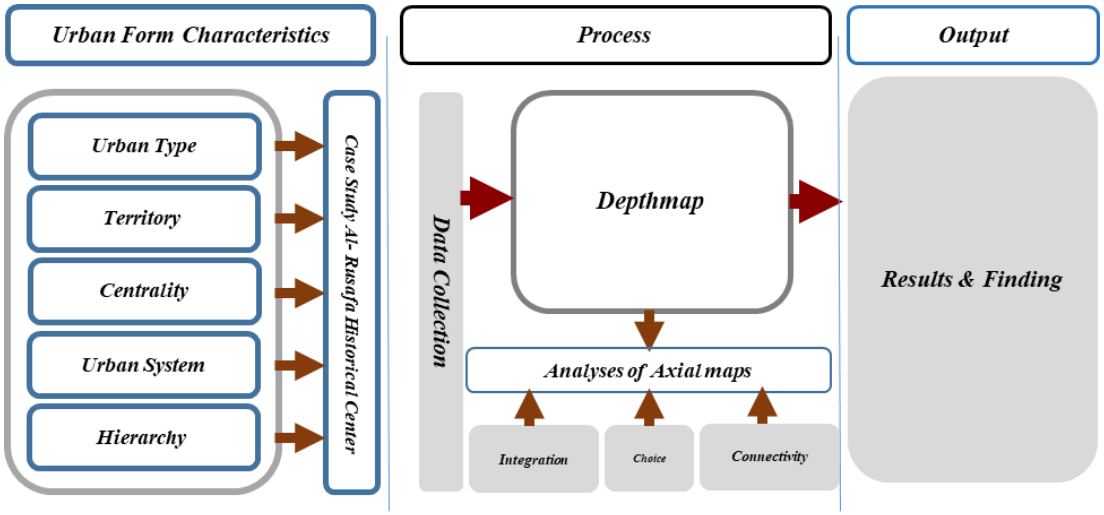


Figure 2. Flowchart of the research methodology

3.1. The Study Area

The study area is located in the center of Baghdad, on the Rusafa side, within the historic Rusafa Center named Al-Murabaea and Al-Aswaq, including districts 104, 106, 108, and 110. It is bordered to the north by the Martyrs' Bridge, to the west by the Tigris River, to the south by Al-Sinak Bridge, and to the east by Al-Khulafa Street, and its area is about 100 hectares. The history of the area dates back to the Abbasid era. The area is characterized by a compact organic fabric consisting of buildings, winding alleys, and spaces (local public spaces). The region was

studied in two morphological stages to achieve the research goal of revealing the effect of C-DNA on the formation and permanence of the urban characteristics of the historical centers in Baghdad, Iraq. Figure 3 shows the study area location.

Figure 3. The study area, Al- Murabaea and Al-Aswaq

3.1.1. The First Morphological Stage 1850:

In 1850, the urban fabric adopted a compact and cohesive organic pattern; this pattern was appropriate to the environmental conditions of the site and the cultural and social determinants of the residents. C-DNA is represented in the region through the form and relationships of the urban fabric as well as the spatial structure, which has graduated from private to public. Due to the region's alignment with the Tigris River, the main alleys have direct contact with the Tigris River space that appears through anchorage (Sharia) to cross to the Karkh side via river transport [35].

3.1.2. The Second Morphological Stage (Present Time):

The urban environment of the study area has undergone many changes and additions. The change in the urban composition of the area began in 1910 with the construction of Al-Rashid Street; this street divided the area into two urban islands. The construction of Al-Rashid Street encountered resistance from the clergy during its early stages due to its impact on significant landmarks in the area, including Morgan Mosque, which altered the street's alignment. Al-Rashid Street represents the central public urban space in the region. It includes administrative, commercial, and cultural activities, thus becoming a place for social interaction between residents and visitors in this area. The buildings surrounding Al-Rashid Street and the main streets consist of four floors, in addition to the presence of the arcade, which is the distinctive element of the street. The separation between pedestrian and vehicular movement characterizes the area. Although streets were built inside and around the area for the passage of cars, pedestrian movement continued within the organic alleys.

The movement network consists of two levels of paths that are distinguished from each other in terms of area and clarity: Firstly, the primary network, which represents public places, occupies the center and its peripheral regions and includes commercial activity; Secondly, the internal network consists of narrow organic alleys that connect the main axes to the residential buildings, and they are of two types: connected axes on both sides (semi-public) and closed-ended lanes (semi-private), which are used as social spaces with some limited commercial activities to serve the residents [51, 52]. The area includes many important landmarks, such as (Murjan Mosque, Sultan Ali Mosque, Al-Adiliyah Mosque, Al-Wafiyya Mosque, the Latin Church, and the Church of the Mother of Sorrows), khans (Khan Marjan), baths, historical markets (Al-Safafir Market, Al-Mustansir Street), and schools (Al-Mustansiriya School), Figure 4 Shows the landmarks in the study area.

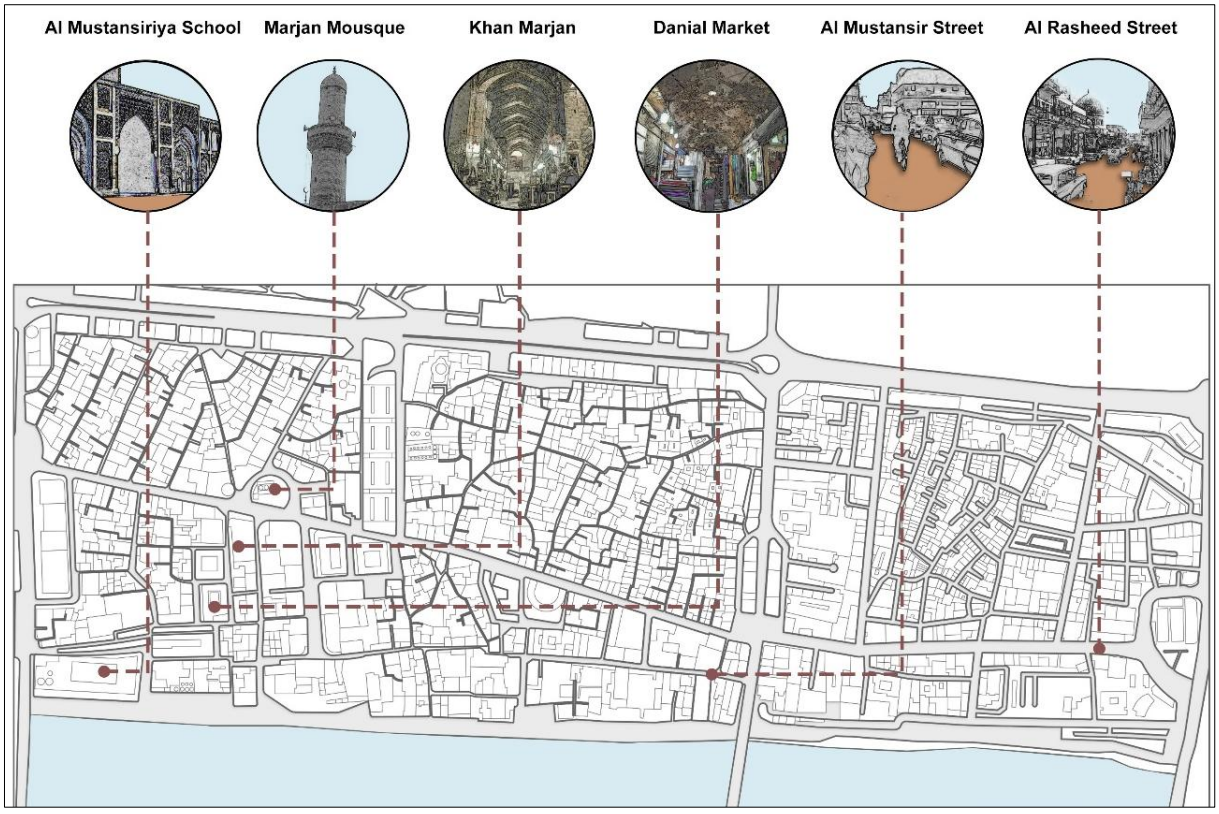


Figure 4. The landmarks in the study area

3.2. Data Collection

Data was collected for the study area through field surveys, site observation, maps, and satellite images, as shown in Figure 3. The study area was analyzed in two morphological stages to reveal the effect of C-DNA in shaping the urban characteristics of historical centers and its relationship to the continuity of those characteristics from change as a result of urban intervention processes.

- The first morphological stage was in 1850, before urban intervention operations.
- The second morphological stage at present after the area has been subjected to urban intervention operations and the construction of streets.
- The research will focus on analysing the impact of C-DNA on the formation and permanence of urban characteristics in historical centers in Baghdad, Table 1 shows the indicators of the impact of C-DNA on forming urban characteristics.

Table 1. The Impact of (C-DNA) on the Urban Characteristics Formation Indicators

Cultural Concepts	Urban Characteristics	Indicators
Cultural Sensitivity & Private Property	Urban Type	The organic type- growth type from bottom to the top
		Human scale
Privacy	Territory	The meeting surfaces and interstitial spaces between the public and private spaces
		Public network (commercial) and private network (residential)
Identity & Social Justice	Centrality	Main and secondary urban foci supporting the central axes
Belonging & Cohesion	Urban System	Urban structure's cohesion
		Urban space network's continuity
Safety & Social Interaction	Hierarchy	Tree-like system
		Narrow and twisting alleys

3.3. Measuring Tools

The research used the program DepthmapX 0.5 to analyze axial maps of the study area to measure the effect of C-DNA on the spatial characteristics of the region. The program calculated those characteristics as follows:

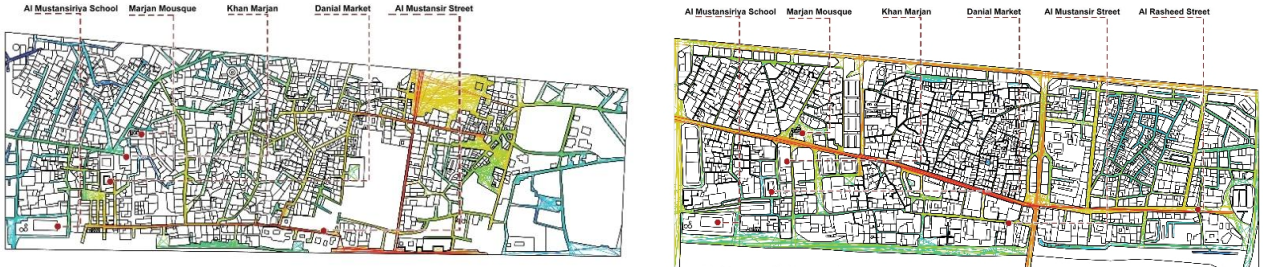
- Drawing axial maps of the region using the program AutoCAD-2023 in two stages, the first stage in the year 1850, and the second at present. The drawing is done by using the longest and smallest number of axial lines possible, and these lines do not intersect with any physical element.
- Calculate and analyze the values of the spatial characteristics (global integration, local integration, connectivity, choice, and control), adopt the Pearson coefficient to measure the correlation (r) between the properties, and then prepare graphs.

4. Results and Discussion

To achieve the research goal of revealing the impact of C-DNA on the urban morphogenesis through the formation of urban characteristics in the historical centers of Baghdad, Iraq, the study adopted morphological analysis in two stages (1850 and the present time) to reveal C-DNA through the analysis of spatial structural characteristics, which achieved a clear effect on the urban structure of the study area.

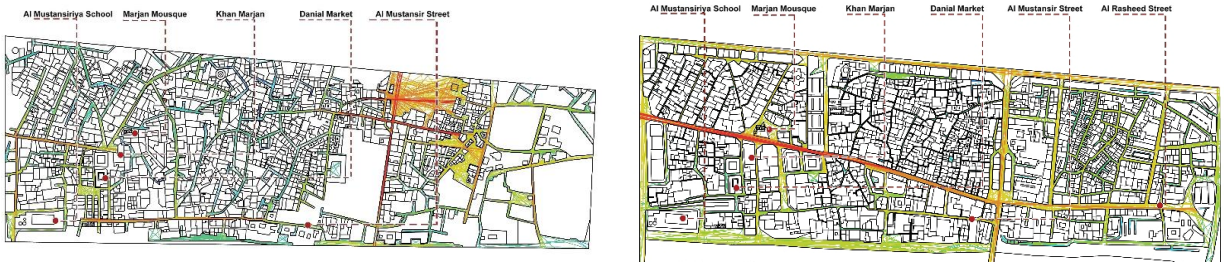
The axial analysis of the first and second morphological stages showed that the high global and local integrations are located in the central region and on the main axes of the study area. In the first morphological stage, the axes (Al-Mustansir Street and Al-Samawal) achieved the highest values of integration due to their connection to the important focal points in the region (Al-Safafir Market, Al-Mustansiriya School, the Khans, and Marjan Mosque) and commercial activities (both wholesale and retail). The value of global integration gradually decreases within residential areas, as they appear in some parts as private spaces for residents, as well as isolated from the movement of strangers and visitors.

Local integration has also been achieved within the residential area due to their relationship with events and activities related to the daily residents' needs. The second morphological stage also recorded the highest integration values on the main axes of the region, as strong integration values were achieved in the streets' axes (Al-Mustansir and Al-Samawal) and markets (Souq Al-Saffarin and Souq Daniel), which represent elements of the region's C-DNA, as well as Al-Rashid Street, which emerged following the urban intervention operations and has the most commercial uses. Unlike traditional cultural heritage preservation frameworks that focus on conserving physical monuments, C-DNA is seen here as an active generative code that shapes spatial configurations and movement patterns. The continuity of the C-DNA of the region has influenced the preservation of public and semi-public urban spaces as spaces for positive interaction, movement, and public events and as meeting surfaces between the local movement of residents inside the residential areas and the global movement inside and outside the historic center (see Figures 5 to 8).



(a) (b)

Figure 5. Comparative analysis of global integration on the (a) first morphological phase and (b) second morphological phase of the study area



(a) (b)

Figure 6. Comparative analysis of local integration on the (a) first morphological phase and (b) second morphological phase of the study area

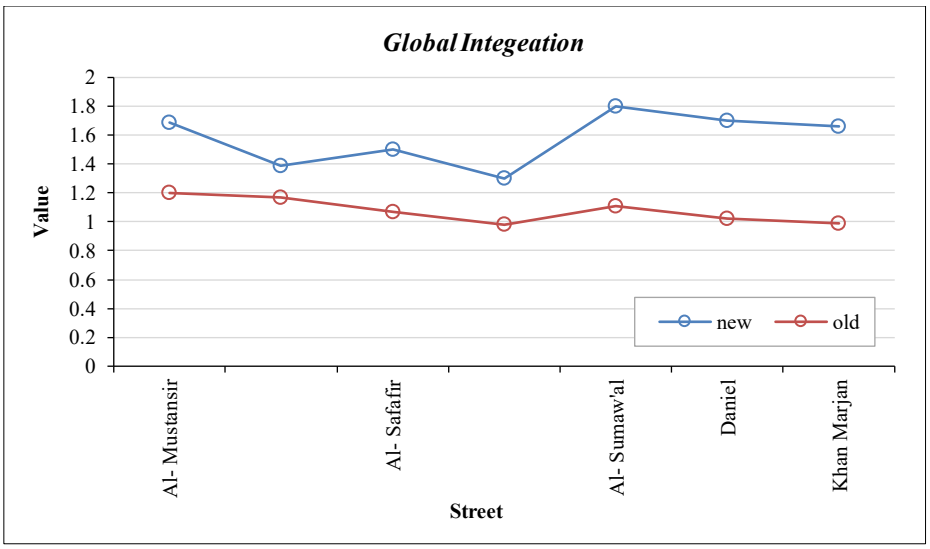


Figure 7. Comparative analysis of global integration in the first and second morphological phases

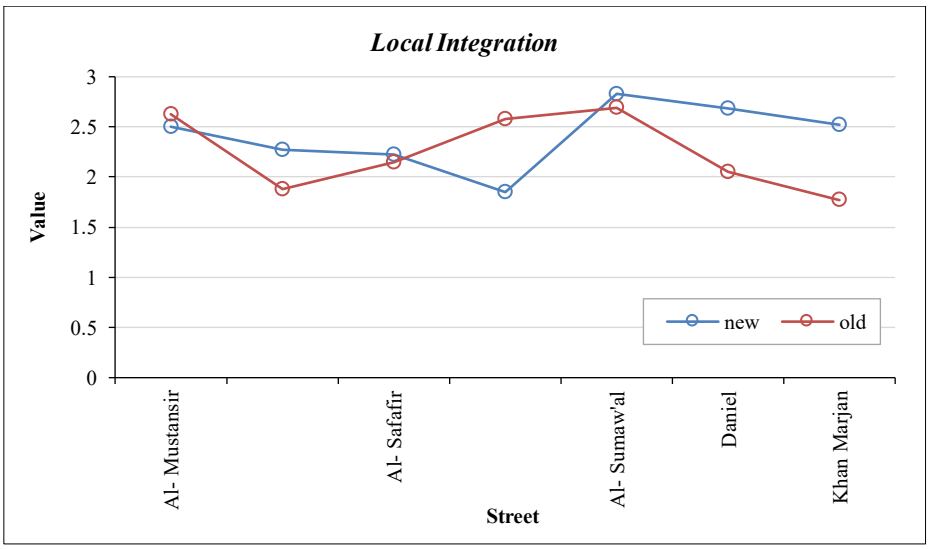
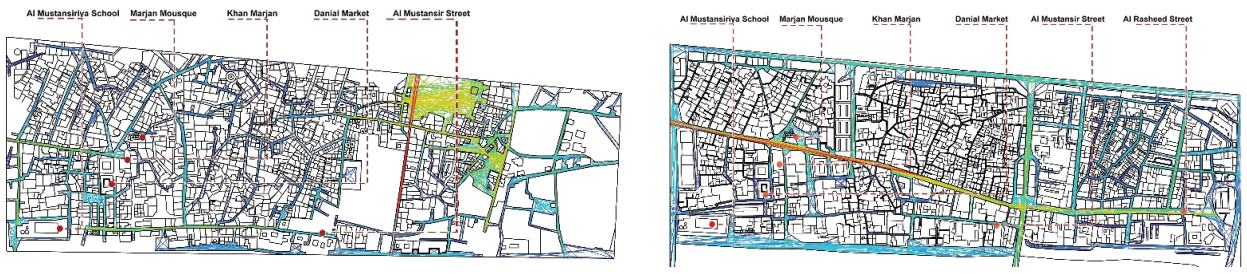


Figure 8. Comparative analysis of Local integration in the first and second morphological phases

The results of the connectivity analysis for the first morphological stage showed high connectivity of the spatial formation in the study area. The nucleus of strong connectivity was achieved in the main axes (Al-Mustansir Street, Al-Samwal Street, and Souq Al-Safafir), indicating that these spaces are distinguished by the coherence and clarity of their spatial organization, as well as their ease of access from all parts of the region's space infrastructure. Despite the construction of Al-Rashid Street, these spaces remained important and organized characteristics of the area's spatial structure. While spaces with weak connectivity were very few, they were spread among spaces with strong connectivity. Based on the analysis, streets with global integration values above 1.5 and connectivity above 4 can be considered "healthy" C-DNA, with accessibility and socio-cultural interaction (see Figures 9 and 10).



(a) (b)

Figure 9. Comparative analysis of connectivity on the (a) first morphological phase and (b) second morphological phase of the study area

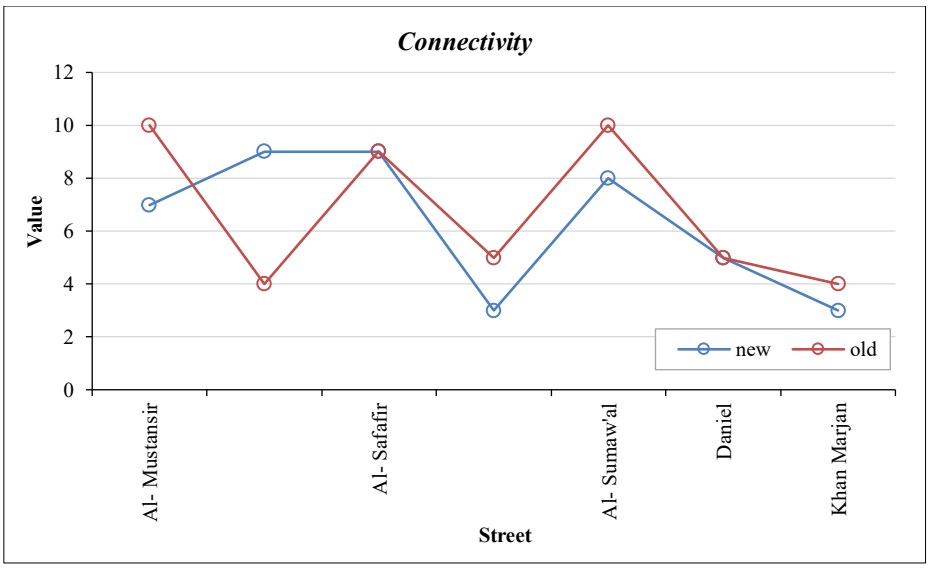
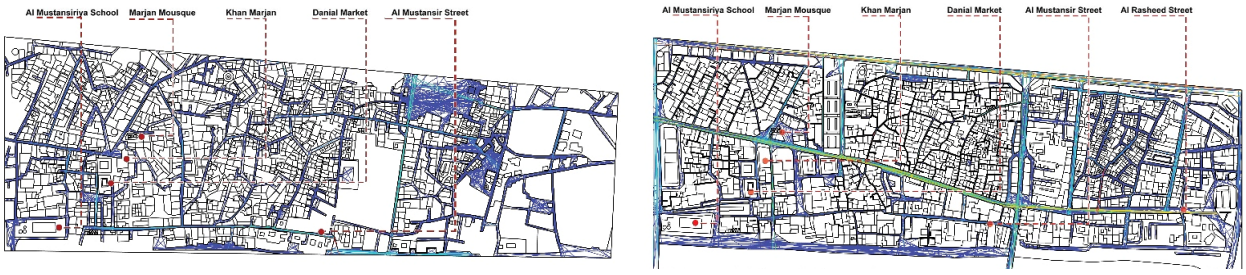


Figure 10. Comparative analysis of the connectivity in the first and second morphological phases

The results of the between-centrality analysis (choice) indicated that the first stage achieved a higher value for choice than the second morphological stage, as the axes (Al-Mustansir and Al-Samawal Streets) and their associated spaces (Souq Al-Safafir, Khan Murjan, and Souq Daniel) achieved the highest values for choice in the spatial formation of the area, thus achieving a high possibility for movement. In the second morphological stage, despite the weakness of the choice value and the environmental determinism in movement in the area due to urban intervention and the construction of the axis (Al-Rashid Street), the main focal points remained with a high choice value because of their connection to daily life and the natural movement of the historic center (see Figures 11 and 12).



(a) (b)

Figure 11. Comparative analysis of choice on the (a) first morphological phase and (b) second morphological phase of the study area

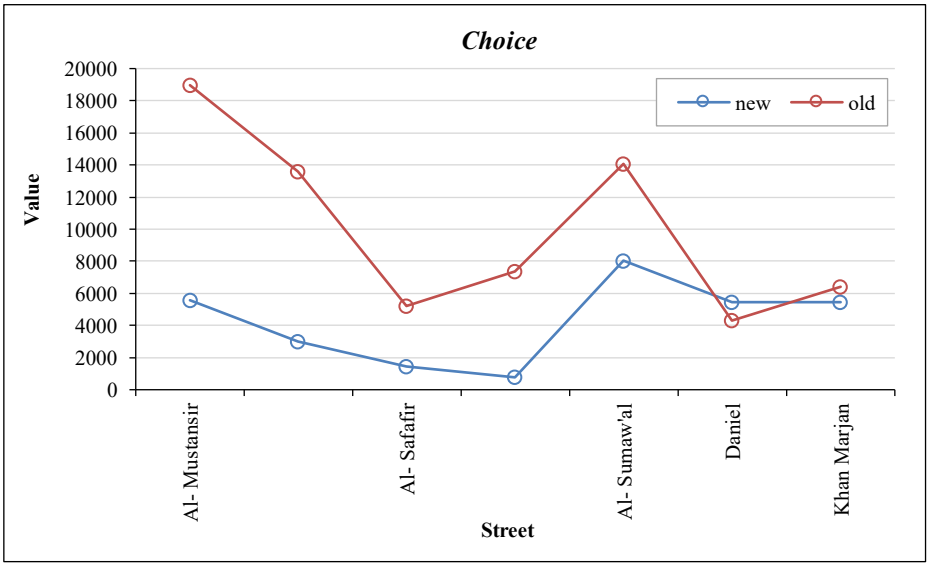
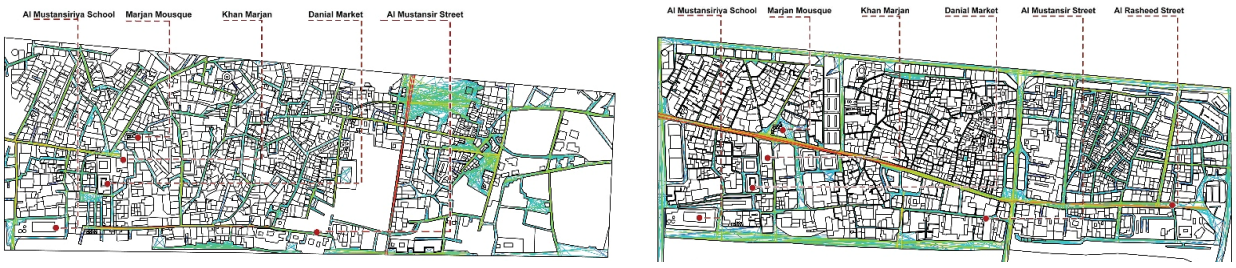


Figure 12. Comparative analysis of the choice in the first and second morphological phases

The nucleus of global control consists of matching the nucleus of high control with the nucleus of local integration of urban spaces in the study area. In the first morphological stage, the main axes (Al-Mustansir Street and Al-Samual Street) achieved strong local spatial connections with all parts of the space system in the region, in addition to the possibility of movement and transfer through those axes to all parts of the space system as a result of their connection to the main foci (Souq Al-Safafir, Khan Murjan, and Souq Daniel) and general activities (wholesale and retail) located in the study area. The weak control nuclei, which are very few, were distributed among the spaces of the strong control nuclei inside the residential areas, as it is difficult to access those spaces from the rest of the parts of the region's space system, in addition to the fact that many of these spaces do not provide a degree of choice to move through them to other spaces. In the second morphological stage, the results of the analysis showed that the core of control in the region is weak, as a result of the weak local connections as a whole and as a result of urban intervention, with the strong cores of control concentrated on the axes and historical foci in the area (see Figure 13 and 14).



(a) (b)

Figure 13. Comparative analysis of control on the (a) first morphological phase and (b) second morphological phase of the study area

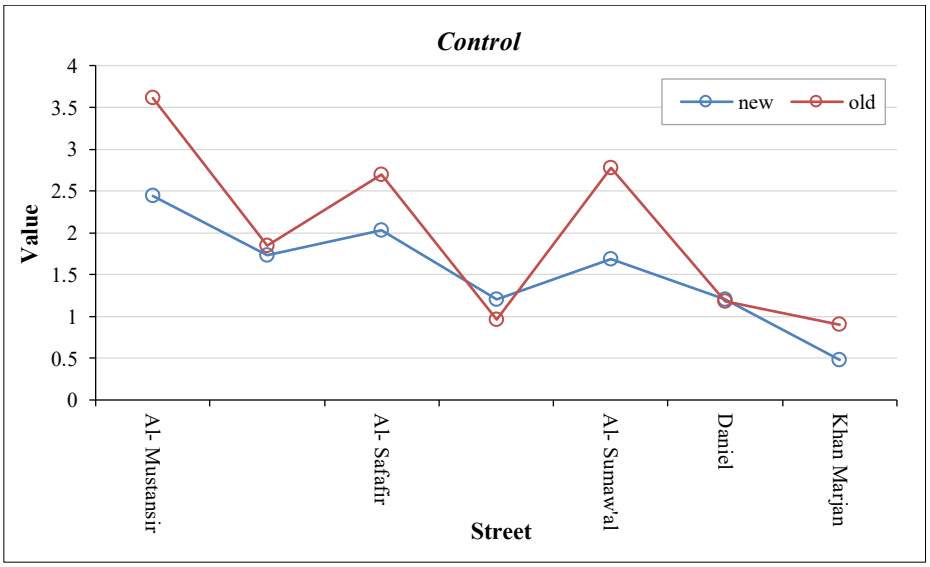


Figure 14. Comparative analysis of the control in the first and second morphological phases

The current study focuses on revealing the C-DNA and its impact on urban morphogenesis through measuring the formation and the permanence of the urban characteristics of historical centers. The study relied on analyzing the spatial structure of a selected area within the historic center of Rusafa to test the research hypothesis "that the formation and continuity of urban characteristics are affected by C-DNA of historical centers," as it differs from other studies that focused on DNA and C-DNA and their impact on the development of physical urban space. Comparative evidence from other Islamic historic cities like Cairo, Isfahan and Fez shows similar tensions between organic street networks and modern interventions. Rusafa is part of this pattern, but with a stronger persistence of centrality because it is still Baghdad's commercial and cultural heart [2, 23].

Analyses of the study area's structure revealed morphological asymmetry and differences in the values of the movement axes, confirming that the area retains the organic pattern, which is one of the characteristics of historical centers in Baghdad that were built using a bottom-up strategy.

The global and local integration indicators showed a clear distinction in the structure and urban space network, achieving a hierarchy and separation between the public (commercial) movement network and the private network of residents. These indicators also created surfaces for a meeting between them, which enhanced the privacy of the residents

of the area and encouraged meetings between them and strangers or visitors to the area. Thus, C-DNA is a generator of the rules of the urban space network that directs natural movement and organizes meetings. Furthermore, social-cultural factors generate spatial differentiation and hierarchical hierarchy in the urban structure.

Through the analysis, it is possible to determine the effect of C-DNA on the spatial centrality of the historical centers, as the historical urban foci (khans, traditional markets, and historical mosques) formed secondary centers that permeated the space network, supporting the continuity of the main axes through clear spatial interconnection, which in turn formed the main centers. While the effectiveness of the penetrating streets (the axis of Al-Rashid Street and Hafez Al-Qadi) was transformed into commercial activities (wholesale and individual), it also achieved integration with the old fabric through the permeability of most internal spaces to those streets, and thus the linear streets became an essential part of urban centralization and the micro-economy linked to daily life for the center and the city as a whole. While vehicular infrastructure is often seen as a disruption, it can also be seen as a new layer of C-DNA, reflecting changing mobility needs. However, this layer will overshadow the pedestrian DNA if not integrated sensitively.

Therefore, it is clear that the underlying natural (cultural) laws controlling the formation and continuity of the study area or the whole historical center, serve to interpret these spaces as social-cultural objects. These laws were reflected in the urban space, as well as its structure and network. Social information is embodied in urban spaces that characterize the spatial culture or cultural genetic pattern, and the urban structure and the spatial network are a variable dependent on values and the cultural process.

5. Conclusions

C-DNA is a method of participating in shaping cities according to available local knowledge. The Depthmap program was used to prove the extracted indicators on the selected study area (Al-Murabaea and Al-Aswaq) to expose the impact of the C-DNA on the urban morphogenesis through measuring the formation of the urban characteristics of the historical centers in Baghdad, and the most important conclusion reached by the research is:

5.1. Regarding the Urban Structure Characteristics

- Urban spatial formation is a translation of the C-DNA of any society. By understanding C-DNA, represented by the socio-cultural values associated with daily life and social and functional practices, the relationships of urban structure and spatial formation can be understood.
- C-DNA acts as a generative system that generates or restricts natural movement and interaction between residents and strangers to achieve privacy or generate encounters and co-existence. The form of the urban structure reflects the cultural pattern of the society.
- The attribute of C-DNA appeared in the form of urban characteristics that fit the socio-cultural factors of the region, as it works to generate a living urban structure and a spatial network that is in harmony with the nature and privacy of the place.
- The research demonstrates that C-DNA is not a static part of the heritage but is a living and adaptive form that engages tradition with modernity as is evident within Rusafa's organic fabric, and later additions as Al-Rashid Street.
- By merging spatial syntax with cultural interpretation, the study adds a hybrid approach to show the intersections between measurable spatial metrics and social cultural practices for culturally specific planning considerations.
- Historically Ottoman and British Mandate regulations on street widening and planning played a big role in reshaping Rusafa. The creation of Al-Rashid Street under British influence was the most significant decision that increased connectivity and disrupted organic permeability.

5.2. Regarding the Urban Space Network

- Despite the urban intervention operations that affected large parts of the historic center, the urban structure and the spatial network emerged as social-cultural objects that retained their structural and spatio-temporal characteristics.
- Integration of spatial centralization locally and globally with the urban structure through the spatial network and its connection to daily life and economic efficiency.
- The importance of C-DNA in the continuity of the main axes as central urban nuclei in the spatial network is due to the presence of secondary nuclei supporting them.
- The sustainable renewal of the urban condition demands policies that recognize the generative rules of C-DNA – the centrality, permeability and hierarchy, so that renewal contributes rather than erodes the cultural DNA of the historic cities as they modernize.
- Fast modernization, especially high-rise developments, will fragment visual corridors and disrupt traditional spatial hierarchies. Unless regulated carefully it will weaken the legibility of the historic DNA.

5.3. Research Limitations

Many determinants were reflected in the knowledge of the researchers in this study, which are as follows:

- The influence of the social structure is closely linked to the formation of society's culture and is responsible for C-DNA's formation of the historical centers. Therefore, we need to study the influence of the social components on the formation of the C-DNA.
- Studying the effect of extending straight streets and trying to connect the historical center with the modern areas in Baghdad's City on C-DNA and the spatial structure of the organic system.
- This study is based on spatial analysis; future research should include social surveys and resident interviews to validate spatial findings with lived cultural practices and perceptions.

5.4. Research Recommendations

The study found the role of C-DNA in shaping and permanence of urban characteristics of historical centers in Baghdad so that it can be applied in other fields:

- Studying and analyzing the C-DNA of cities is one of the basic foundations before urban intervention to develop the urban environment in a way that match the nature and culture of society and the specificity of the urban fabric.
- Identifying the components and C-DNA that have a role in the process of continuity and flexibility of urban space and network in historical centers to accommodate current and future changes.
- Future work could include pedestrian flow counts, mobility surveys and 3D visibility graph analysis (VGA) to capture the experiential dimensions of walkability. Integrating historical cadastral maps and land-use datasets will add more temporal depth to the findings.

6. Declarations

6.1. Author Contributions

Conceptualization, M.M.H. and S.F.K.A.; methodology, S.F.K.A. and D.A.; software, N.H.A.; validation, D.A., M.M.H., and S.F.K.A.; formal analysis, S.F.K.A.; investigation, M.M.H. and D.A.; resources, M.M.H., S.F.K.A., N.H.A., and D.A.; data curation, M.M.H. and S.F.K.A.; writing—original draft preparation, S.F.K.A.; writing—review and editing, N.H.A. and D.A.; visualization, N.H.A. and M.A.J.A.; supervision, S.F.K.A.; project administration, S.F.K.A.; funding acquisition, N.H.A., S.F.K.A., and D.A. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available in the article.

6.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

6.4. Conflicts of Interest

The authors declare no conflict of interest.

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