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The Swarm City - Characteristics of the Swarm Intelligence System in the Traditional Arab City

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ABSTRACT

Specialized architectural studies based on the swarm concept have emerged for nearly two decades. The formation formula based on swarm intelligence is beginning to emerge as a methodological and conceptual basis for a range of generative architectural design strategies. The intelligence of the swarm and the logic on which the swarm system is based can be seen in traditional urban formations, where traditional cities follow models of sustainable natural processes, which best match the simple rules of the swarm system. Accordingly, the research problem was recognized as **"the lack of a cognitive background for the characteristics of the swarm's intelligence system and its function in the structure of the traditional Arab city fabric".** Therefore, to solve this problem, the significance of the natural systems and their impact on the sustainability of cities was determined, and the definition of the swarm city, and the theoretical base that supports the features of the swarm intelligence system was developed based on its items extracted in the analysis of the traditional Arab city and the structure of its historical fabric. The architectural dependence of swarm intelligence is not an attempt to mimic nature only but to examine the generative potential of swarm logic and draw emerging behavior in generating complex attributes in form, organization, pattern, or structure. Traditional Arab cities, in the structure of their historical fabric, follow the typical characteristics of a swarm intelligence system, in which systems of city formation are embodied according to characteristics of multiple agents, emerging collective behaviors, and highly coordinated self-organization.

1. INTRODUCTION

The ecosystem in which we live has gone through millions of years to develop complex strategies that are flexible to environmental changes. Emerging detections from how natural biological systems use adaptation strategies to their environment could demonstrate crucial to the architectural field, and in specific, how this emerging knowledge can illustrate the ways natural structures swarm reproduce and regulate themselves to design cities. Thus, the thought of gathering natural and artificial principles of design and regulation has the possibility to result architectural systems that are harmonious and responsive to their context and the context of a living biological system.

By observing the behavior of naturally occurring swarm systems, swarm intelligence looks to simulate the strength, adaptability and effectiveness of these regularities, which emerge as a consequence of multiple reactions between simple elements. The swarm intelligence, which has been discovered and detailed over the past two decades by scholars from diverse disciplines, can be seen in traditional urban formations and that these cities follow the processes od sustainable natural models. Accordingly, this research sought to **"disclose the characteristics of the swarm intelligence system affecting the structure of the traditional Arab city".** To solve the problem of the research and accomplish its goal, steps have been adopted, including:

- Clarify the importance of natural systems and their imitation - swarms in the sustainability of cities.
- Definition of swarm city - swarm urbanism.
- Investigating and obtaining the most significant indicators of the ideal swarm intelligence in general, and its conceptual and experimental links at the urban level, and then building a comprehensive cognitive framework.
- Applying the obtained framework to a selected urban sample (The case of the traditional Arab city) and extracting the most significant conclusions from the results.

2. MIMICRY OF NATURE AND SWARM CITY - URBANISM

Architecture has a recurring interest in nature and the imitation of nature, the synergy between nature and the artificial by recognizing the new conditions of co-evolution and the common rhythms of man and nature, and both living and nonliving elements. It is therefore not surprising that swarms are increasingly designated as referential metaphors and organizational analogy within architectural rhetoric [1, 2]. Swarms have been studied extensively in nature using the behavior of birds, ants and bees as examples of human reactions in systems and societies. The basis for these theories is that swarms operate following unpretentious rules as highly flexible systems. The system is self-regulating in its readiness

and response to varying conditions. It evolves emerging patterns and structures to reduce the effect of change, complexity, and uncertainty [3]. Thus, maintaining existence or dealing with alterations in their environments, can be considered as complicated adaptive systems [4].

For the city, as a complicated adaptive system, it gives us the characteristics and behavior of the swarm for a spatial guide to city adaptation, which can develop smart city designs, that can be modified for uncertain future claims regardless of whether they develop slowly or occur suddenly [5]. Cities, like a swarm, have evidenced successful in replicating themselves, attracting immigrant populations from all over the world, and heartening, in general, higher birth rates and longer lifespans from within their surroundings. Cities, like termite colonies, have a sort of emerging intelligence to learn patterns in human behavior [6].

Architectural design research based on the swarm concept emerged nearly two decades ago in experimental practices. Swarm Logic, which emerged from the work of emerging practices and academic institutions, has been used across a wide range to include abstract pattern generation, the formation of non-linear structural networks, the self-organization of urban systems, and the generation of form and pattern for multi-agent design models [2].

The expression swarm urbanism has been utilized extensively in the field of design. It almost denotes a form of the 'swarm effect' technically [7]. Neil Leach addresses how the concept of the swarm can be applied to urbanization. Where (Leach) defines according to the theories of emergence put forward by (Steven Johnson) in his book "Emergence" (2009). A city is described in terms such as organisms: The city functions as an adaptive and dynamic system, founded on interfaces with neighbors, indirect control, feedback loops, and type perception. It displays collective intelligence such as ant colonies, bird flocks, neurons' networks, or the global economy [6]. In short, the city runs within a kind of "swarm intelligence" [8]. Cities, like biological systems or super-beings, have a form of emerging intelligence, which is the ability to store and retrieve information, to discern and respond to patterns of human behavior. The human mind is aware of the complex patterns that make up the city object through the undisclosed relationships and interactions between streets, buildings, and transportation networks and how these networks are formed over time. The city, as with any living system, must be able to adapt constantly to survive [6].

Swarm systems ecologies involve the interplay of their component systems (such as software, infrastructure, formal, structural, or decorative systems). Behavioral design methodologies allow for the perception that they are behaviors that are coded within interconnected systems. The development of swarm Urbanism thus challenges the concept of urban design as a group of sequential judgements at decreasing scales and instead proposes an instantaneous process in which local judgments cooperate to produce a complicated urban design system within swarm urbanization systems, where instead of designing a model that satisfies a set of standards, urban requirements are programmed in self-organizing agents to negotiate this input. Accordingly, this concept of urbanization generates systems that are flexible and robust enough to respond to the ever-changing political, economic and social pressures of urban development [9].

Swarm behavior is characterized in nature as highly flexible and complex adaptive systems, operating according to simple rules, being self-regulating, and evolving emerging patterns and structures. Thus, applying these features to urban-spatial systems could be beneficial to improve the adaptive capability, resilience and sustainability of the whole system, and better prepare for and respond to potential environmental events.

Urbanism - swarm city can be illustrated by introducing the city to the emerging collective intelligence - "swarm intelligence". A city functions as an adaptive, dynamic, and resilient system founded on the interfaces between its constituent systems (such as programmatic, infrastructural, formal, structural, or decorative systems), feedback loops, perception of human behavior patterns and the complex patterns that make up the city, and control indirect, where local decisions interact, as coded behaviors within interconnected systems, and self-organizing agents to respond to the pressures of ever-changing urban development (political, economic and social).

Therefore, the research will go in the subsequent paragraphs to clarify the knowledge aspects of swarm intelligence, in general, and what is related to the city, its systems and structure in particular.

3. SWARM INTELLIGENCE

This section is meant to clarify the swarm intelligence system, its distinctive characteristics and general principles, in addition to a set of related concepts and dimensions.

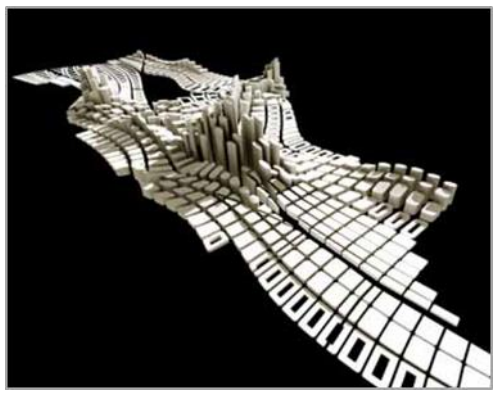
3.1 Characteristics and principles of swarm intelligence

Typically, when speaking of swarms and swarm intelligence, designers refer to emerging rhythmic processes (waves) regarding the sharing of pictograms of frozen or moving swarm topologies. As informational visualization becomes an increasingly global language of systems, events, and trends, these images of swarm-assembly take on a more public and political task. It is not just statistical summaries of human and non-human societies that essentially aggregate over time, it is also self-representations of these societies that take and adopt, as always in collective representations, Model agents for a structural topology in which individuals measure their progress. The image is the systemic recursion interface between trace and tracing, between the individual unit and the community.

Swarm intelligence has recently emerged as a general theory to describe collective behavior, while swarm behavior itself is not new as an important research area within the study of complexity. (John Holland) laid the foundation for the development of research into swarm intelligence in conjunction with the work of (Stuart Kauffman and Christopher Langton). Key figures in the development of swarm intelligence, such as (Marco Dorigo, Guy Theraulaz and Eric Bonabeau), have investigated the self-organizing systems in environment as examples for comprehending other behavioral structures. Thinkers have been influenced by the tradition of Deleuzian "pluralism", such as (Manuel DeLanda), who was also influenced by early ideas from the (Santa Fe Institute). (DeLanda) established New Materialism theory when he began to identify a situation in Deleuze's work, where the concepts of Deleuzian pluralism and self-organization meet [2].

Swarm intelligence studies were made to deal with natural and synthetic systems made up of many people. They focus, in particular, on a range of performances that stem from individuals' local interfaces with each other and with their surroundings. Many modes of systems were investigated in this field like ant and termite colonies, fish flocks, bird flocks, wild animals flocks, groups of people, some multi-robot systems, as well as some computer soft wares that are designed to handle the optimization problems and the analysis of data [10]. Swarm behavioral patterns in nature are managed by standards of self-organization and emergence, instead of planning and control by an external force.

When these standards are incorporated into a complicated spatial system, the system could begin to display characteristics of a swarm, as a reaction to interferences and stimuluses will vary its form, but not content. The components of the system will remain the same, but they will react more responsively to varying and unclear conditions, thus improving their adaptive capability [4]. Swarm intelligence, in addition to the natural systems upon which we build it, is highly dependent on another important concept (in addition to self-organization): It is stigmergy, which permits swarms of simple, earnest individuals to act and react corresponding to simple policies to display highly complicated group behaviors, such as trail following and path finding behavior in ant colonies [11], as can be seen in Figure 1.



The urban strategy initially generates trails using a "swarm logic" technique based on the principles of ant pheromone pathways. Parametric techniques are later used to generate building envelopes in response to these initial pathways [12].

Figure 1. Redevelopment of the airport site in Taipei

In general, a distinctive swarm intelligence system usually owns the following characteristics [10]:

- It contains several individuals,
- All its members are somewhat consistent or belong to some types,
- Interactions between individuals are founded on simple standards of conduct that use only domestic data that individuals swap straight or through the surroundings,
- The general performance of the system resulted from the interaction of individuals with others and with their surroundings, in other words, collective performance is self-regulated.

The basis for the cohesive elegance and flexibility of swarms is a highly complex form of swarm intelligence that is based on the domestic reaction of individual agents that leads to complicated global performance. The command generated from above is not executed but rather stems from the bottom-up reaction between agents of the swarm. This complicated model is progressively comprehended as basic logical systems as various as flocks of birds, insect colonies, human social networks, and even city processes [2]. As stated by Van Ginneken, the collaborations which occur between a vast number of alike and freely moving agents are independently and rapidly towards each other and their surroundings leading to the occurrence of a new collective entity and a greater intelligible unity of the higher-order [4].

One of the most distinguishing characteristics of a swarm intelligence system is the high level of coordination shown by the constituent personnel, coordination that is achieved without the need for a central control point or any external direction. Despite the lack of responsible individuals for the group, the swarm as a total can display intelligent performance. This is the outcome of the interface of spatially adjacent individuals operating based on simple standards [10], as all the active members of a swarm act as a single individual in a node, and an individual actor communicates only with his immediate neighbor and all neighbors, who follow the same principle [13]. Another potential distinguishing characteristic of a swarm intelligence system (in the robotic system if properly designed), is the possibility of being developable or scalable via a new addition to the swarm [10].

The characteristics of a typical swarm intelligence system can be determined founded on the principles of self-regulation and emergence, and as follows:

- **Multi-agent: It contains many agents - individuals who are comparatively similar or belong to some types, and move freely.**
- **Collective behaviors: The general performance of the system comes from the interaction of individual agents with each other and with their surroundings - from the bottom-up; this leads to complex global behavior and the evolution of a new cooperative entity and a larger, cohesive unity of the Supreme Order.**
- **High coordination: Interactions between agents depend on clear demeanor rules that use only domestic information exchanged by individuals straight or through the surroundings, using decentralized control, meaning that the behavior of the group is self-regulated.**
- **The ability of being developable or scalable: Through the new addition.**

The research noted that various studies and theorists present a wide range of concepts, theoretical models, and overlapping dimensions that are directly or indirectly related to the swarm intelligence system, to include these concepts about emergence, self-organization, Rhizomatic Urbanism ... etc. that present a form of swarm intelligence and/or the frequency of the logic on which it is based. Some concepts will be clarified in the next section concerning the main research objective and provide a good idea of this system.

3.2 Conceptual correlates of swarm intelligence

3.2.1 Emergence and self- regulation

As a general definition of 'emergence', (Wolf and Holvoet) provided the following practical definition: The system emerges when there is a cohesive emanation at the macro level that arises from reactions between fragments at the micro level. Such evolutions are considered novel with respect to the individual parts of the system [14].

Emergence has turn out to be a very common expression in

modern architectural dissertation, however, it is worth noting that the expression itself does not essentially denote contemporaneous design subjects. On the opposite, it can be said that the emergence can be seen very clear in conventional urban structures because they are exactly the forms of less self-conscious urban combinations that characterize the evolution of conventional communities from primitive villages to Chinese alleys or Brazilian neighborhoods, that best conform to clear principles of emergence, like “pay consideration to your neighbors”. These formats of urbanization comprise a comparatively consistent range of processes, in which the individual element does not be obvious, but correspond to the prevailing logic of its surroundings [8]. Steven Johnson, in his book "The Connected Lives of Ants, Cities and Software", describes the city as an appearance of emergence, where he notes the city "like any emerging system" is an arrangement in time. Additionally, similar to any other populace made up of a vast number of smaller distinct components, it exhibits bottom-up cooperative intelligence which is more complex than the performance of its portions [7].

It is pertinent to notice that self-regulation is an occurrence usually seen in connection with the broader theory of emergence. It is the procedure that provides emergent results and, as Batty declares, is the trademark of emergence. In terms of distinguishing between emergence and self-regulation, (De Wolf and Holvoet) explain: Emergence and self-regulation happen mutually in most systems considered in the literature, and an amalgamation of self-regulation and emergence is suggested in highly complicated (multi-agent) systems. Self-regulation requires augmentation to enhance a particular function or characteristic. Modest individuals cannot dictate such a complicated system, so coherent global performance must arise from relations between individuals. Conversely, it can take a complex (multi-agent) system to show emerging behavior. Due to the complexity, it is impracticable to execute an elementary assembly on a system like this that causes emergent properties. The only opportunity for obtaining intelligible performance at the macro level is to allow this performance to emerge and arrange independently, i.e., self-regulation [14].

Self-regulation can be defined as a group of energetic procedures in which structures or decisions emerge at the overall level of an organization from the reactions between its lower-level constituents, deprived of being obviously implied at the individual level. An overall arrangement is an emerging property of the system more exactly than a property executed in the system by the influence of an exterior regulation [15]. As a general definition of self-regulation, (Wolf and Holvoet) provide the following practical definition: Self-regulation is a dynamic and adaptive practice in which systems attain and preserve structure on their own, without exterior regulator. An organization could be a spatial, chronological or operational structure. No outside regulation indicates the lack of trend, operation, intervention, or pressure from outside the system [14].

Self-organizing systems have the following main characteristics [15]:

(1) Dynamic; the construction of spatial patterns, in addition to their perseverance, require continuous reactions between the members of the system and their surroundings. These reactions reinforce the optimistic reactions that generate collective assemblies and work for their survival versus the adverse reactions that manage to remove them.

(2) Emerging characteristics; they demonstrate more complicated characteristics than the simple influence of separately agent. These characteristics come from the nonlinear grouping of relations between the members of the system.

(3) Along with emerging characteristics, nonlinear relations guide self-organizing systems into divergences. Divergence is the emergence of a new steady solution when some parameters of the system change (factors that vary experimentally). This matches a qualitative variation in group performance.

(4) Finally, self-regulating systems could be multi-stable. In other words, for a specified group of limitations, the system could attain diverse steady states relying on the original circumstances and random variations. These fluctuations often result from the random component of individual behaviors; in such cases, structures do not appear only through indiscriminate, but indiscriminate is also a critical element because it permits the deterioration of homogeneous situations.

For example, Leach explains in his study "Swarm Urbanism" that cities are physical effects of patterns of social behavior that operate over time, governed by the principles of self-regulation, they should be appreciated as a mixture of procedures and as areas of directional streams that adapt to different inputs and drivers, such as some self-organizing systems. As shown by Rem Koolhaas in his research "Lagos", the outward disorder of the life of city could be comprehended as a highly developed self-organizing system that arranges, organizes, categorizes and reuses consistent with completely distinct economic standards. In fact, for the stricter pattern of a self-regulating urban system, we may consider beyond Lagos and head toward a city like Hong Kong that sits within a financially driven culture, unrestrained by tough historical bonds. It cannot be understood, with its intensity of social interactions, as disordered and confusing groups of disparate events, but as a highly complex communication of interconnected micro-systems operating within an understanding of global swarm intelligence [8].

Emergence and self-organization are explained by simultaneous processes. Emergence is the appearance or occurrence, dynamic cohesive behavior at the macro-global level from the nonlinear reactions between the elements at the micro-local level, independently organizing, which leads to bifurcations - solutions, and new and different stable states depending on the change of some factors and initial conditions with random fluctuations in individual behaviors without change. Self-organization is the continuous and adaptive dynamic processes and mechanisms for acquiring and maintaining the structure of the system at the macro level, in the form of an emerging property of the system, without external control.

Cities can be seen as manifestations or expressions of emerging behavior, not different from the behavior of the swarm, and as self-organizing systems governed by principles of self-organization. The self-organizing global design arises by negotiating a set of design decisions and different drivers or local behaviors, encoded in the individual factors that interact within the city-swarm system. Thus, these methodologies represent a shift from designing something to designing the underlying behavior of its formation (designing the behavior underlying its formation).

3.2.2 Rhizomatic urbanism, assemblage and machinic phylum

It has been suggested that the rhizome model has much to

contribute to the discourse on urbanization. What makes rhizomes so suggestive is that they are always relational [8]. In their important research, (Thousand Plateaus, Deleuze & Guattari) present a theoretic model that reverberates thoroughly with the rationality of emergence. As an example, they indicate broadly to pluralism, the wolf pack, and the logic of the crowd. At the same time, one of the basic beliefs of their viewpoint is populace intelligent - the idea that populations are not individuals but rather a matrix of form production [7]. Deleuze & Guattari's use of the expression rhizome to define a complicated set of relations that connect concentrations, but do not have a hierarchy or center and that is constantly changing (building, deconstructing, reconstructing). It reappears as a reaction to exterior and interior incentives. A rhizome is a method to understand and describe any occurrence, from language to communal reactions to policies. The character of the roots is the nature of the mobile matrix, made up of parts of different nature, forming interdependent and parallel links, consistent with as yet undefined transitional pathways [14].

In a swarm system, there is a chain of communication and reactions that occur between people, buildings and their components. All components send and receive information in real-time to process incoming data and give new results. People are data carriers, too, and the information keeps flowing according to (Oosterhuis), if we apply this idea of information processing to buildings and architecture, we realize that buildings are constantly absorbing information, processing information and producing new information. Buildings are always connected to this flow of information. They are connected to other buildings in cities, connected to the world through interaction, and connected to users through user interfaces. These processes, driven by building components, play a major role in the evolutionary process of shaping and transforming information and spaces. All this information is preserved in the swarm system, they are never lost, but they are only transformed [13].

The city can be understood as forming roots with its residents. This begins an interesting means to understand the relation between people as agents within this system and the structure of the city as a type of exoskeleton for humanoid processes. We need to differentiate between the city as the site of physical formation, as a mixture of building trails, and the city as the place of spatial performs. The former could be recited in terms of the accumulation and increase of matter deposits, and the other can be recited in terms of the movement of agents whose ease of movement is restricted due to these physical layers. It is as if the city was shaped by recording the motives of human habitation or activity. These motives are controlled and manipulated by this fabric in the form of an endless response cycle between the population and the city. With time, the structure of the city develops over communication with its residents, and conversely, the population develops through interaction with the fabric of the city [7, 8].

The rhizome model refers to the intelligence or logic of swarm and emergence through the terms of plurality, matrix, and the mutual-cooperative interaction relationship. The nature of rhizomes is like a moving matrix, made up of organic and inorganic parts, and forms symbiotic and parallel links according to transitional pathways. The term "rhizome" is used to describe a complex set of relationships, linking non-central or hierarchical forces that are constantly changing (by building, deconstructing, and reconstructing) and re-emerge as a reaction to extrinsic and intrinsic impulses.

Here the city is understood as a network of space and information flows that adapt to different inputs and drivers such as self-organizing systems. To imagine how the structure of the city developed as a physical shape in response to the motives of housing - occupations and human processes, as spatial practices of agents, and that these motives are specific and affected by the physical layers of this structure in the shape of a continuous reaction cycle between the population and the city; It is a form of mutual assumption and informational and spatial transformation, where the population represents the matrix for the production of the city.

There are many other suggestive terms in Deleuze & Guattari's writings, such as assemblage, echoing the logic of swarm intelligence. Assemblage can be described as the loose relationship of individual elements that come mutually to create a single body; however, this body is not steady or united. It is a compilation of objects in one context, yet a compilation that refuses stratification. It works, as Ansell Pearson notes, as a central plurality that is subject to constant travel and diversity. So, what is accumulation? It is a plurality that presumes many varied expressions that establish the links and relationships among them, going through the various genders, ages and kinds - nature. Therefore, the assembly unit is only co- operative; It is interdependence and harmony [8].

(Shane), in "Recombinant Urbanism", refers to Deleuze and assemblies concept, especially the conception of rhizomatic assembly. As said by Shane, rhizomatic assembly blends the concept of an individual's narrative path with interconnected or shared information of a group, forming a collective awareness of individuals' collective experiences in communicating with one another. (Shane) also referred to the rhizomatic assembly as a way of treating with what he realized as a recent (complicated and emerging) urban situation. The Deleuze and Guattari theory of grouping treats with the relationship of the portion to the entire of assemblies, wherever assemblies are a set of portions that does not own characteristics that are generally recognizable. To be suitable as an assembly, the portions must react with each other in such a mode as to give each its properties, the properties are irreducible to parts. In other words, an assembly is recognizable, albeit dynamic, developing unit that consists only of the reaction of its portions, but cannot shorthand in terms of its portions [14].

Assemblage deals with emerging processes and, more specifically, the connections between the micro and macro scales, thus providing methods for dealing with emergence and self-organization. The assemblage is an emergent whole and dynamic that consists of the reaction of its portions, but it cannot be compacted in terms of its portions that do not have recognizable properties in general, where it depends on the individual path with the interconnected or common material of the party and the formation of a collective awareness in the communication of individuals with each other in a way that gives each of them his characteristics.

Another related term to the logic of swarm intelligence is the machinic phylum. For Deleuze and Guattari, it is a

substance in a state of flux and diversity at the same time. It is a carrier for singularities. The matter is to be comprehended here in the sense of morphogenesis as acting through a form of self-regulation. As said by Manuel DeLanda, the expression machinic phylum could denote both self-regulating practices in common and groups in specific in which the influence of these practices can be combined. Meaning, the expression denotes any populace (insects, molecules, atoms, and cells) in which total dynamics are controlled by individuals (attractors and bifurcations); In other words, it denotes the combination of a set of components into an assembly**,** this means more than just the sum of its parts, those that display universal properties that their components do not possess [8].

The concept of the machinic phylum denotes both the practices of self- regulation, generally, and the groups, specifically, and in an integrated manner, and a repetition of what was put forward in the previous concepts, which explain the combination of a group of components into an assembly that is more just than the sum of its portions, and presents global characteristics that its individual components do not possess. Thus, the belief that the total is bigger than the summation of its portions reflects the principle of emergence.

4. LITERATURES REVIEW

In this section, the research presents several studies, intending to enhance and complete the theoretical framework related to some indicators of the swarm intelligence system in general and its applications at the urban level in particular, that permit them to be put side by side to become a broader theoretical base.

4.1 A Study (Kokkugia, 2010 [9])

The study mainly deals with behavioral design approaches, which arose from a perception based on swarm intelligence and work through the self-organization of multi-agent structures. Designing intent works in these approaches through the reaction of local performance instead of obvious depiction or parametric operation of system and organization.

Behavioral design approaches characterize a change from "shape inflicted on the material" to "shape arising from the reaction of local objects within a complicated system". Design through nonlinear behavioral systems encounters hierarchies entrenched in the structural design, and gives radical insinuations for the production of tectonics and their associated effects. The impetus for exploring these methodologies is an interest in both solving complex design problems and the formal effects or organizational characteristics that these processes generate, where the design moves from the direct invention of form or organization to the intensive processes of formation - the organization of form effectively. This is the shift from explicit formal processes to designing the rules that underlie the generation of behavior and thus influence it.

The study identified two primary mechanisms through which any agent operates within the behavioral design process: the agent of architectural material and the agent that organizes or restructures architectural material. This difference can be understood by analogy with the behavior of social insects. The cooperation of ants in forming chains or bridges is an example of an agent acting as an architectural or structural material. Instead, the formation of termite mounds involves the reorganization of matter through a bottom-up set of rules that define a stigmergic relationship between clay, pheromone and the interaction of a group of termites.

Behavioral design methodologies intrinsically resist the discrete formation of the tectonic hierarchy that dominates modern architecture and assemblies of contemporary parametric components. The progressive nature of these systems refocuses tectonic interests on micro-scale assembly. This is not to say that behavioral design methodologies will involve a complete hierarchy normalization, but rather than pre-determining the hierarchy and based on hierarchical metrics, it can be understood as an emerging property of a decentralized system, or as (DeLanda) describes, it is meshwork negotiation and hierarchies.

The study showed that ending the hierarchy in the ecology of feedback is clearer in applying the logic of the swarm to urbanization. The sequence of scale and density is imperative, of course, within the urbanization. However, the swarm logic developed for Kokkugia's schematic proposal for Melbourne Docklands, Figure 2, assumes opposition to the pre-structure of hierarchical urban design models. Instead, all features of the urban structure are seen as controlling agents or (forces), enabling them to interact simultaneously, giving rise to emerging hierarchies as a complex outcome of their self-organizing process. Within this project, this agent works through each of the previously discussed mechanisms of behavioral formation: Firstly, by utilizing design agents for the self-regulation of urban material, and secondly, by encoding behavior in urban objects and topologies.

Agents within this system are not public. Instead, there is an ecology of systems that interact with each set of agents programmed to their desires and information. In this first category, agents distribute the program through a process of self-regulation of stigmatized development. This pattern of collective performance is comparable to the sense that termite colonies use to create their mounds. The other class of agents operate similarly to the self-regulation of lower pathway systems that arise from the interaction of slime mold cells. This class of urban agents is mainly utilized to produce circulatory infrastructure systems [9].

The Agent Generating the topology network: The ceiling surface is generated by a network of agents capable of self-organizing and reconfiguring their network topology [9].

Figure 2. Taipei Performing Arts Center. Designer Kokkugia, 2008

4.2 A Study (Roggema, 2012 [4])

The study focused on a proposal for a spatial planning framework, where city spaces are seen as swarming to simply adjust to extraordinary changes. The study presented a swarm planning structure that contains the following four sections:

(1) Two levels of complexity: It is represented by two levels of the city's performance of self-organization: The entire city level and the individual level elements. The ability to self-regulate at the whole system level is improved through the implementation of tactical interferences, whereby the system as a total could be better affected. These sites could be determined based on network examination, as the intersections in the network are very closely linked to other intersections and the most significant intersections are the very possible spaces for interfering. At the second level of individual elements, such as canal, building, and road, each element is separately accredited with self-regulating capabilities. Each discrete element has unique characteristics, and consequently must be attributed to the accompanying abilities.

(2) Five Layers: Five layers have been distinguished, namely: focal points, networks, unintended area, natural assets and developing forms of use. Not all parts of the city is varying at a similar speed. When spatial components of comparable changeability or time-based tempo are related with a particular spatial level, spatial dynamism can be taken and transitions can be enhanced, predicted, or facilitated. Each of the five levels is likewise related to a spatial extent. Rapid alteration frequently occurs on a lesser scale, while gradual alterations occur at greater spatial scales.

(3) Non-linear processes: It means the emergence of other non-linear practices in the diverse parts of the swarm planning structure. Emerging patterns and correlations often take place in networks and between denser intersections. Tipping Points, which are described as the instant when the system turns from one condition to a new condition, could be determined spatially as the most significant intersection point in the formation (installation) of systems. In an unintended space, the effects of tactical interference and the tipping point could be alleviated. The effect of the interference on its surroundings may form recent spatial models through self-organization. The suitability of city spaces is largely linked to natural assets. These assets, such as nature, pure water, clean energy, and food frequently promote from a steady environment in which natural practices can improve. The alterations will occur very gradually in these systems till the system discontinues functioning correctly. At that instant the system changes to a different situation where it could function steadily. Developing forms of use progress as a consequence of self-organization. This occur most simply when many components are close to each other.

(4) Two planning processes: By describing two ways of using ingredients in the planning process. Firstly, approach is "from small to large". In this way, planning begins with an analysis of the slowest, the natural assets. This composes the foundation on which options can be made for the second, slower layer, networks. This layer posteriorly determines the playing field for the nodes, after which occupancy forms may clarify, and finally, the remaining unplanned area. Secondly, approach is the "partner group". Analysis of the first layer, networks, in this case, occurs first. Based on this analysis the densest and significant nodes are determined. These nodes are best suited for implementing a tactical intervention. The first and second layers are also visible as the layers that affect the city spaces as an entire. When the most significant nodes are specified and spaces for tactical interventions are chosen, the spaces around these nodes remain unplanned to permit the effects of the intervention freely. These spaces can be used as outdoor spaces for natural assets. Finally, the forms of occupancy emerging in the fifth layer are identified and added up to the plan [4].

4.3 A Study (Roggema & Dobbelsteen, 2012 [3])

A swarm planning approach is the focus of the study. A city's post-carbon scenario (the period next fossil fuels' dominance) and pre-adaptive scenario (the period previously preparations to expect environmental changes) are both critical. The study dealt with the theory of swarm planning and its development to be capable to plan for increasingly changing environments. Learning from the behavior of swarms helps to evolve a planning approach that can handle non-linear processes as well as self-organization.

In urban designs, the swarm theory is applied in a few cases. When landscape function as a swarm, they can flexibly change their configuration while the elements that compose them remain unchanged. With this ability, landscape can better adapt to external shocks. Two main pillars of Swarm planning theory are the use of complexity principles and a layered approach.

System as entire and individual ingredients are both used to increase adaptability by using two levels of dual complexity. The system as an entire can be more affected when it has been pushed out of equilibrium by external compression. Bifurcation occurs at this point, and multiple stable states are possible. This interference with the spatial system must influence the system in the right direction at this critical juncture. Emergent behavior and self-regulation are both attributed to individual elements in complex adaptive systems. Reconfiguration of the system can be achieved by using the appropriate intervention and the components of the system. The adaptive capacity of regional plans is enhanced when spatial planning facilitates these processes.

For the layered approach, spatial elements are linked to specific temporal rhythms. The following classes were distinguished:

- The substrate layer, it's expected that erosion processes and water systems will change over time.
- Network layer encompassing transportation, energy and ecology. Nearly a century has passed since this layer was formed.
- The human occupancy layer, which includes residential and industrial works, and changes occur during 20-50 years.
- The public domain layer, motivating urban nodes and centers as strategic points; Estimated intervals of less than 20 years are possible [3].

It is clear from the above, that the studies that dealt with the swarm intelligence system, have illustrated new important aspects concerning to the types of agents within the behavioral design processes concerning the agent of the architectural material and the agent of organizing and restructuring the architectural material. It highlighted aspects represented in the components and approach of spatial planning - swarm, which in their indicators reflect some characteristics of the swarm intelligence system, in addition to providing a deeper understanding and

interpretation of some of the characteristics arising from the intelligence of the swarm.

5. THEORETICAL FRAMEWORK

Based on what has been offered of contemporary propositions and studies specialized in defining swarm city as well as conceptual and empirical connections, a theoretical base and a field of knowledge has been provided that can be adopted in defining swarm city as "the city that is illustrated by presenting the emerging collective intelligence - swarm intelligence by adopting the typical characteristics of a swarm intelligence system in terms of multi-agents, collective-emergent behaviors, and highly-coordinated self-organization. A city, like biological systems or superorganisms, functions as a dynamic, adaptive, flexible, and complex system that can scale and develop emerging patterns and structures based on interactions between its component systems (such as programmatic, infrastructural, formal, structural, or decorative systems), informal feedback loops, perceiving patterns of human behavior, the complex patterns that make up the city, and indirect control. Local decisions interact as coded behaviors within interconnected systems and self-organizing agents to prepare for and respond to the changes and pressures of urban development (political, economic and social) and to sustain existence".

Accordingly, the main terms and their secondary indicators have been identified, around which the characteristics of the city swarm intelligence system are concentrated, extracted by organizing the previous knowledge, represented by:

- **First: the general characteristics of the swarm intelligence system**
- **Second: the typical characteristics of the swarm intelligence system; Include:**
  - The multiplicity of agents: which is determined by the substratum and types of agents.
  - Collective emerging behaviors: represented by the processes of global behavioral design, and the appearance of global behavior design.
  - High self-organized coordination.

Table 1 illustrates the terms of the theoretical framework for the characteristics of the city swarm intelligence system.

Table 1. Characteristics of the city swarm intelligence system/ Source: (The researcher)

The general characteristics of swarm intelligence system		
Highly flexible, adaptive and dynamic complex systems. Self-organized, with the ability to develop emerging patterns and structures, and increase. Prepare for and respond to changes and pressures of urban development (political, economic and social), and to maintain existence.		
The typical characteristics of the swarm intelligence system;		
Multiplicity of agents	Substratum of Agent	Agent homogeneity Patterns of Agents
	Types of agents	Architectural Material Agent Architectural Organizing and Restructuring Agent
Group emerging behaviors	Global behavioral design processes	The emergence of a complex coherent and dynamic comprehensive - global behavior (at the macro level) that results from the interactions of individual agents (at the micro-level) with each other and with their environment. The emergence of bifurcations - new of solutions and stable states depending on individual changing behaviors and feedback loops. The development of a new collective entity and a larger, coherent unit of the supreme order in the form of the integration of a group of elements into an assembly, and presenting global characteristics that its individual components do not possess.
	The appearance of global design behavior	Rhythmic processes emerging -as waves- of frozen or moving topological layers. Systematic repetition between impact and tracing, and between individual unit and society. Free belonging to a group of individual components in one common, integrated and harmonious context (to form one unstable body). Elegance and coherent fluidity Central pluralism in constant flux and diversity A moving matrix with symbiotic, parallel, and complex bonds
Self-organizing high coordination	Reliance (interactions) on simple rules using shared local information between individuals, directly or across the environment Using decentralized control and organizing independently	

6. PRACTICAL STUDY

The research adopted the descriptive-analytical study method to achieve the goal of the research and reach the desired results, by studying the case of the traditional Arab city and the possibility of achieving indicators of the characteristics of the city swarm intelligence system. The subsequent paragraphs explain the analysis and study of the traditional Arab city and the structure of its historical fabric according to the variables of the theoretical framework items, which are shown in Table 1, concerning the typical characteristics of the swarm intelligence system specifically, which include multiple agents, collective-emergent behaviors, and self-regulating high coordination.

6.1 Multiplicity of agents

Swarm city formation systems are embodied in patterns of agents, as well as include two types of agents: agents of architectural material, and agents of organizing and restructuring architectural material. The traditional Islamic cities of the Arab world appear a variety of assets and outgrowth patterns. These were conditioned on the one hand by external factors as pre-existing settlements, intentional choices of site and developments and changes predominant in dynasties, and on the other by internal factors as

morphological principles embedded in individual architectural ingredients and the formation of the urban fabric. For example, spatial choices have generally depended on prevailing trade routes, geopolitical considerations, availability of natural resources (such as permanent water supplies and back farmland), and in some cases, the religious significance of certain places [16]. The special character of the Islamic religious system and its practice can only influence social systems and living ways. This was inverted in specific spatial options, essential urban layouts and artistic notions, that formed the material aspect of the built environment [16, 17]. Figure 3 illustrates the basic notions and principles (Qawa'id Fiqhiyah) of the Islamic law which administered the basic logic for the operations of alteration and up growth. An important objective of these principles is to equalize among neighbors when anticipations, requirements, and desired alteration lead to advantage for one owner at the expense of his neighbor. The impact of these principles by the time resorts to fairly reconcile the competing and occasionally incompatible claims between neighboring proprietors [18].

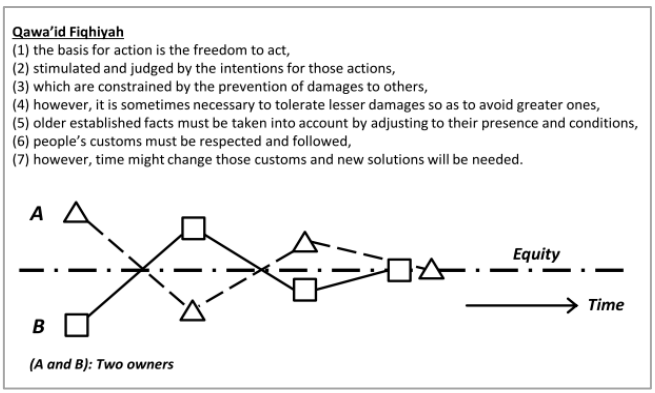


Figure 3. The Islamic law (Qawa'id Fiqhiyah) principles which administered the basic logic for the operations alteration and up growth [18]

As it is found in the surviving structures of historical cities such as Aleppo, Damascus, Fez, Tunis and Baghdad, these urban structures, admittedly, represent a late stage in the development of the urban form, spanning over the past three or four centuries, yet they reflect the permanent principles and attitudes rooted in traditional community life and in some tribal customs, which can be traced back to the khittat system, as was practiced in the first centuries of Islam. The precise visual reference system relates to the accepted and codes of social behavior within specific urban parts. Each individual area carefully retains its specific spatial character, while interacting with neighboring units through distinct architectural means, such as intermediate entrances, internal corridors, thresholds and connecting doors. Hence, the impression of meandering through a seemingly endless series of interconnected rooms within a very clear and homogeneous urban world [16].

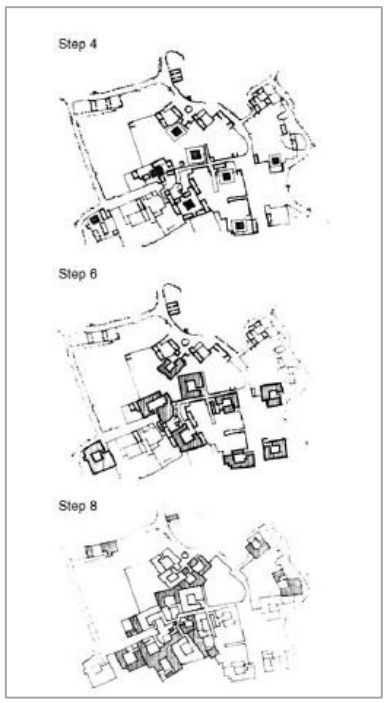
6.2 Emerging group behaviors

First: Global Behavioral Design Processes; It can be explained by:

- Coherence, complexity, dynamicity and comprehensiveness emerge from the reactions between individual agents (at the micro-level) and their environment (at the macro-level). This can be seen through the emergence of the city from the resolutions made by the different actors participatory in build and renewal directly inside its built environment. As with any complex system, the development of the built environment is analogous. The evolution of the built environment in the traditional Islamic city can be explained by the characteristics of living systems. Traditional Islamic cities grew as a result of a set of rules that established the boundaries that the people within them were expected to observe and obey. Because of its adherence to these rules, the system is able to accumulate and absorb experiences through growth and experimentation [19].

Having an understanding of how traditional cities came to be is essential and beneficial. In John Holland's book, (1995), he identifies adaptive and aggregate agents to explain how the complex adaptive system works. Individual agents' actions are governed by a set of rules, making it easy to talk about the tactics used by agents. When these agents react with each other, they form new hierarchical levels by adhering to certain rules, which can then be aggregated again to form even more levels of hierarchy. Traditional built environments have a tendency to change their rules as time goes on. Complex adaptive systems, on the other hand, are non-linear, dynamic, and capable of generating a wide range of outcomes while still adhering to predefined rules. Despite the numerous alterations, particularly at the micro level, the city's overall character and identity remain intact [18].

Figure 4 clarifies a typical succession of the emergence of an exemplary traditional Islamic fabric, depending locally applicable codes and habitual practices. Site studies of successions appearing up growth and alteration are fundamental to conception how the codes function and the nature of the aggregation operation [18].



What is shown is only three steps out of a series of eight. Step 4 displays the layout of the courtyards, step 6 is the position and layout of the rooms around the courtyard, and step 8 is the final formations [18].

Figure 4. A typical example of how a group of houses in a traditional Islamic setting would develop

- The emergence of new solutions and stable states in the process of interaction of agents with each other and with their

environment, depending on the changing individual behaviors (perception of human behavior patterns) and feedback loops. This can be seen in the process of gradual growth, in which settlements often absorb pre-existing agricultural and irrigation pathways, which, once absorbed, became subordinate to the residential units. By the same token, the former undifferentiated open spaces reappeared in a fragmented manner within the housing units, in the form of enclosed garden courtyards belonging to the newly built single houses, which were often more spacious than the houses in the crowded inner city (in the poor neighborhoods of crowded cities) [16].

Another significant phenomenon that happened in traditional cities is feedback. There are two forms of feedback: positive and negative. The first repeats the same action over and over and is linked to guiding codes. Negative feedback is the one that which can deal with indiscriminate changes, and a way to reach balance and fairness. Emerging systems are within limits determined by the rules. The capacity of the system to learn, grow and experiment stems from its obligation to these rules. These systems learn from mistake. Therefore, society can rectify its mistake and regulate itself [18].

- The evolution of a new group entity and a larger, cohesive unit of the Supreme Order in the form of the integration of a group of elements into an assembly, and presents universal characteristics that its individual components do not possess. For example, joining individual units, whether houses or clusters, was not a matter of loose juxtaposition, but involved structural assimilation that would gradually absorb the basic building blocks and incorporate them into the larger urban system. This process of gradual integration would not have been possible without the consistent use of an omnipresent cellular composition system in each of the conjoined, interconnected, or overlapping areas of closed circulation systems, repeated at different sizes and different hierarchical levels of the urban structure.

Merging and overlapping separate architectural structures into more complex patterns created an exceptional sense of internal unity and homogeneity that is evident from the overall view of the residential fabric of traditional Arab cities. The secret of coherence and inner unity within a rich variety of individual formal expressions depends on the presence of vertical series of comparisons and correspondences as a key principle of inductive or deductive structural constructs. Looking at the urban fabric as a whole, one discovers the great connections between public and residential buildings, both in terms of the items of complex individual structures and how the composite elements are connected and combined into larger compounds. The main difference in connection state appears when it comes to switching from the public domain to the private domain [16].

The typical urban form of historical Arab cities thus grew as a compact collection of smaller and larger areas, each equipped with an appropriate cellular infill, as well as internal open spaces, access systems, and shared facilities assigned to the respective groups and individual users. The fact that all these micro-elements of the urban form is common. The same structural principles, despite the different functions, made them perfectly compatible. Its self-centered and self-sufficient character was greatly facilitated by the formation of inner courtyards, air columns, and horizontal cohesion, in favor of their integration into larger urban components that were complete in themselves at every stage of development, in space and time [16].

Second: The appearance of global design behavior

The appearance of global design behavior is embodied in the essential qualities of the urban form of the traditional Arab city. As a result, the city can be likened to a large, but cohesive, palace, with everything under one roof. There would be mosques and khans for teaching rooms and guest rooms; markets with rows of storerooms would represent the interconnecting interior corridors of a mosque. The private quarters of this collective urban "house" are provided by the residential quarters, which are organized according to the same principles as public spaces, but with greater emphasis on articulating intermediate corridors. Several major axes connect the city's central multifunctional assembly to the outer gates, ensuring connectivity within and outside the walled city.

The result is breathing and animated urban structure, showing a radiant inner unity fundamentally different from the sterile uniformity produced by mechanical modes of addition or division. The city transforms into a vibrant multi-focal pattern, embracing dozens of self-contained sub-centers, all of which share the wholeness of the overall system. This structural system translates into a paradoxical physical experience, a feature of most traditional Arab cities: one always feels at the center of things, in whatever sub-unit of the complex urban structure may be.

The essential qualities of urban form are a natural result of distinct human attitudes, cultural conventions, and synergistic processes that create a vibrant built environment, and in doing so define the links that function between the parts and the whole. Such interrelationships can operate at different levels, for example, between man and society, between the world of man and the universe, or between individual buildings and the city as a whole. The multiple interconnections between the different levels are a major source of cultural richness [16].

6.3 Self-Organizing high coordination

Self-organizing high coordination can be explained by relying (interactions) on simple rules, using local information shared between individuals directly or across the environment, and using decentralized control and autonomous regulation. Several authors have stated that historical Arab cities exhibit either spontaneous or planned urban models, the former associated with the most popular urban formations (sometimes of rural origin), and the latter determined by the official plans of palace cities. While there is some truth in this distinction, one may also argue that the planned palace cities were a response to military concepts and princely representation needs that were not typical of the common Muslim city. Here, the powerful social order of Islam (which is both practiced in conjunction with strong customary laws), the conspicuous absence of formal civic institutions and the subsequent empowerment of private communities and self-organized social groups, led to a particular type of space management that was reflected in processes of 'organic' growth, i.e. an urban form that has grown from within, so to speak, conditioned by incremental decisions at the grassroots level, rather than succumbing to imposed external plans [16].

The ruling authority was tasked with laying the groundwork for the city's future. City walls and gates, the Great Mosque's location, the Palace, and the Central Market District's paving were all affected by decisions made by the ruling authority, as were the main streets that connect these structures. From other sides, the city arose naturally as an outcome of the resolutions and activities of its inhabitants, who, when they built homes

and other buildings, reacted to the circumstances existing in the neighboring ownerships by modifying their design. Over time, changes happened as the proprietors adapted to the neighbors, particularly the adjacent buildings. In short, the system was self-organizing and adaptable [19]. As a result of their decisions and actions, individuals who start new complexes or small farms have the ability to self-organize. Adapting their design and planning decisions in this way, they take into account the conditions on nearby properties. Complexes change and adapt over time as their owners adjust to changes in the surrounding and contiguous properties. For example, new farm boundaries and compound walls will necessitate paving and widening of existing paths and streets [18].

Powerful micro-communities, many of which are descended from the same tribe, are responsible for the development and maintenance of the neighborhood structure. Local mosques, one or more small baths, communal ovens, and street fountains were all common amenities in these self-reliant communities, each of which included a representative segment of the community and was in charge of managing the neighborhood's basic infrastructure. These facilities were often built in conjunction with a neighborhood's central heating system. The Muhtasib, on the other hand, had control over the supermarket's public space, which was managed by commercial and craft businesses [16].

7. DISCUSSION AND CONCLUSIONS

The research examines the issue of simulating biological-natural systems and their importance in the sustainability of cities in light of exploring the swarm city by presenting swarm intelligence, behavior and the logic on which it is based by adopting the characteristics of the swarm intelligence system in general, and following traditional Arab cities models of sustainable natural processes that match the characteristics of the ideal swarm intelligence system in particular. The swarm city functions as a dynamic, adaptive, flexible, complex, and self-organizing system that can scale and develop emerging patterns and structures, as well as prepare for and respond to changes and pressures of urban development (political, economic and social) and to maintain existence.

While mimicking nature is an important part of the process, it isn't the only goal of architectural swarm intelligence. It represents a shifting approach from designing something to designing the underlying behavior of its formation (designing the behavior underlying its formation). The ability to design compelling urban projects through swarm intelligence remains somewhat of an open question. Where the global projects and experiences presented in this research at the urban level reveal the abilities of their designers to draw the emerging behavior in generating complex characteristics in form, organization, pattern or structure. For the swarm logic to have a profound effect on the city, it must have a fundamental influence on the nature of the resulting architecture, and the possibility of making a decisive difference in the formation of the spatial, formal and organizational characteristics of the city.

The research presented a theoretical framework that supports the characteristics of the swarm intelligence system in general and as an influential factor in the structure of the traditional Arab city in particular. The research found, according to the analysis of the selected case study, that the traditional Arab cities follow, in the structure of their historical fabric, the typical characteristics of the swarm intelligence system according to **the characteristics of multiplicity of agents, emerging collective behaviors, and self-organizing high coordination.**

The traditional Arab city-formation systems are embodied in patterns of agents and include two types of agents: agents of architectural material (represented by component systems) and agents of organizing and restructuring architectural material (represented by coding behavior in urban elements and topology). According to the global behavioral design processes, global behavior appears (at the macro level), coherent, dynamic, complex, resulting from the interactions of individual agents (at the micro-level) with each other and with their environment, depending on design decisions and different motivations or local behaviors encoded in the individual factors that interact within the city system, it leads to the emergence of bifurcations - solutions and new stable states depending on factors, initial conditions, random fluctuations in individual changing behaviors and feedback loops. Thus, the development of a new collective entity and a larger coherent unit of the Supreme Order in the form of the integration of a group of elements in an aggregate form that deals with the links between the partial and total scales and presents global characteristics that its individual components do not possess. On the other hand, the basic characteristics of the urban form of the traditional Arab city embody many appearances of global design behavior such as the integration and harmony of a group of individual components in a single-common context, coherent fluidity, central pluralism and continuous diversity, and a dynamic matrix with symbiotic and parallel-complex links. Finally, the highly-coordinated, self-organizing characteristics of the city appear by relying (interactions) on simple rules, using local information shared between individuals, directly or through the environment, forming collective consciousness in people's communication with each other, using decentralized control and organizing independently.

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