Evolutionary Design Guidelines for Filling Historical Urban Gaps *(paper)*

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Abstract
Many parametric and algorithmic emergence methods have been applied to evolving architectural typologies and urban morphogenesis efficiently. Nevertheless, they have failed to realize the same performance in the historic environments, due to their inability to meet multiple design challenges. Therefore, investigation more intelligent, scientific approach for historical urban interventions is becoming an imperative request. The focus of this research is on developing evolutionary design guidelines for filling (empty or destructive) historical urban gaps with adaptive Multifractal forms, through addressing the social and morphological design challenges, and re balancing the role of urban connectivity and complexity values, by increasing their interacting capacity with the host environment through self-organizing change depending on the feedback.
The research will perform a comparison between two different case studies: the historical center of Aleppo and the modern center of Cosenza, which have been developed recently to derive the most important evolutionary design guidelines, that could face multiple design challenges:

A) Definition and optimization of building genotype and phenotype;
B) Filling gaps approach and parameter in the historical and modern contexts;
C) Urban generation techniques in spatial and complexity systems.

These guidelines assist in transforming the theory of geometrical emergence and urban morphogenesis as computational processes into a **practical emergent urbanism**. Thereby brings new life into the Evolutionary Design (ED), making it a powerful player in transforming and shaping the historical and modern urban environments.

Despite that, the research results are not expected to be realistic since there are more approaches and perspectives that need to be involved. This research assists on the ongoing debates about the efficiency of evolutionary multi-criteria optimisation in engineering design, which opens the door toward achieving a holistic and integrative design approach by incorporating more objectives and criteria (functional, environmental, material behaviour and biological design). This is due to the advanced capacity of multi-objective optimisation to facilitate the generation of the complex systems. Which does not preclude that final decision, as can address non-quantifiable measures such as aesthetics, which is left to the designer.

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Key words: evolutionary design, building genotype and phenotype, morphological approach

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Premise
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The research will perform a comparison between two different case studies: the historical center of Aleppo and the modern center of Cosenza (which have been developed recently) to derive the most important evolutionary design guidelines that could face multiple design challenges:

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1. Introduction
Parametric and algorithmic architecture design has evolved recently complex shapes

stemmed from different approaches and perspectives (environmental, functional, structural, biological and morphological). Most of these shapes could not adapt themselves to the “host environments”, in particular to the historical one because of omission of multiple design challenges. While from the other hand the traditional generation mechanisms have utilized linear form finding processes to study urban phenomena from the ‘top down’, which considered an obstacle, confronting emerging creative processes of urban morphogenesis, due to the inability to move the creative acts from static events to dynamic transformations. That’s why techniques of scientific complexity, such as chaos theory and other ‘new’ methods of emerging, such as cellular automata, agent-based modelling, spatial metrics, artificial intelligence, neural networks, non-linear simulation, complexity theory itself and fractal generation represent pivot means to study architecture and urban phenomena from the ‘bottom up’ [1]. These techniques allow for achieving harmony, homogeneity and coherence of a nonlinear feedback system by involving the approach of scientific complexity, based on the role of two morphological key factors: complexity and connectivity that govern the growth orientation of urban contexts [2]. What, shows how self-reproducing systems change their structure and behavior through the interplay between the genetic code (complexity and connectivity) and its interactions with other populations [3].
According to Jencks, complexity theory is based on the sudden emergence of new organizations, even if it cannot fully explain the miraculous power behind it [4]. Chris Langton (1992) has explained the general idea behind this concept, in his emergence diagram, 1992 that shows local variables interacting together at the object-level, and the sudden emergence of the global structure above it, which then feeds back on the local variables. According to Gershenson (2008), a complex system is one in which elements interact and affect each other so that it is difficult to separate the behavior of individual elements [5]. This interacting capacity for achieving a balance between ordered and chaotic systems, interprets the spreading of this approach into various scientific fields, especially at the efficient design and bio-inspired geometrical development. The growth of a city took hundreds or even thousands of years if we consider the growth of a city as a self-organizing biological-like organism, organic urban forms will take hundreds or even thousands of years to emerge and evolve until the current morphology, co-evolving with the human bio-functional interrelated evolution. In particular, these urban forms will show an inside fractal nature. Courtat considered that city's growth is guided by needs in local distribution and communication among its parts [6]. These needs justify the complexity dimension investigations at the localized level, thus, articulate the imperative need to embody it in the Evolutionary Design (ED). Salingaros argued that, for understanding the intricate connectivity (needs) of the living urban fabric, it is necessary to undo the damage happened by erasing the fractal properties of the traditional city [7].

Despite that recognition of fractal dimension as a valuable tool for shapes’ description have been considered since the paper of Mandelbrot entitled by How Long is the Cost of Britain? Statistical Self-Similarity and Fractional Dimension [8], but the fractal analysis of cities started with Fractal Cities by Batty and Longley (1994). It is worth to mention that many logarithms and approaches of how to estimate fractal dimension exist, each giving, more or less, different results. Therefore, picking up the appropriate technique should be done carefully [9]. Michael Batty, (1994) was the first who proved the fact that fractal dimension is a valid descriptor and classifier of urban growth [10]. Many researchers of the field, who performed a serious of analytic studies (Frankhauser 1998, Jeffrey West 1999, Salingaros 2001, Alexander 2004, McAdams 2007, 2009, Tucek 2013, Swaid 2015), have followed his approach. Demonstrating the capacity of Lacunarity and fractal analyses to measure the morphology of complex shapes, and describe the degree of geometry hierarchy (complexity value), and the degree of urban interactions (connectivity value) [2]. Tucek & Janoska (2013), performed a significant study on the same topic, showed how spatial processes can be described in terms of the fractal dimension. And moreover, how those descriptors can be used to view the city not as a series of different states in time, but as a changing system with its own dynamics.

The research has performed three consecutive phases, the first phase developed an innovative local dimension analysis, which forms the core for estimating localized morphological changes of emerging geometries and urban interactions, as a base of fitness function design, see [11]. The second phase created a new epistemological framework for urban morphology, by using evolutionary techniques to have a set of rules for creating different genotypes of architecture and urban forms, see [12]. The third phase developed a new space-filling mechanism based on Bio-Inspired Design Tool (BIDT) for emerging Multifractal forms that adaptively self-organize themselves depending on the feedback. The BIDT tool adopted Evolutionary Multi-criteria Optimization (EMO) to address contradict objectives based on a weighted fitness function design, see [13].

This paper aims to develop an evolutionary design guidelines for filling historical urban gaps, by performing a comparison study between two contrasted cases (in terms of their host environment, architectural typology and urban morphology), the historical center of Aleppo and the new center of Cosenza, to derive the most important evolutionary design guidelines that address multiple morphological design challenges. In particular, the research is needed to resolve the following key questions:

A. How to generate a genetic description of an organism or its genotype towards resulting its phenotype?

B. Which mechanisms and parameters fit mimicking the evolution of complex adaptive systems such as historical context?

C. What are the efficient rules/laws, which could self-organize organism’s components? Moreover, how could define their evolution in specific stages?

2. Interdisciplinary Methodology

The research adopts both quantitative and qualitative comparative methodologies based on the empirical results that are gained from the previous parts (have been performed recently). This methodology embodies interdisciplinary approach from mathematics, artificial intelligence, urban studies, and architecture. The research proposes guidelines targeting only the socio-morphological obstacles that are addressed in the research. On one hand, these obstacles formed critical challenges for the urban interventions and their performance in the historical contexts and prevented them from exploiting the powerful tools of the computational design to create prognoses for the future, on the other hand.

For achieving the paper's aim, three stages will be investigated A) Creating the genotype’s and phenotype’s definition and optimization. B) Filling gaps’ approach and parameter in the historical context. C) Urban generation techniques in spatial systems.

2.1 Creating Genotype’s and Phenotype’s Definition and Optimization

The research hypothesis is based on considering historical urban structures as complex as living bio-organic species, with similar attributes, advantages and characteristics, and behaving in the same way towards adopting and adapting to different environmental conditions by changing their “genetic code”, co-evolving with the human bio-functional interrelations evolution [12].

Therefore, the research in the first phase started with very well identification of the critical problems that confronting creation the genotype and phenotype’s definition, by defining two interrelated relations (spatial and functional relations) form together the constituent components of the genetic description. Then the research developed a novel technology for A) Assessing current functional relations by urban interactions (connectivity) analysis, and assessing spatial relations by self-similarity structure (complexity) analysis; B) Thresholding the Urban Connectivity and Complexity (UCC) dimensions by applying two algorithms: Local Connected Fractal Dimension (LCFD), and Sliding Lacunarity (SLAC). This technology represents a paradigm shift for the very first time (using LCFD & SLAC) in architectural and urban ED towards transformation of social and morphological analyses from qualitative to quantitative measurements, and establishes a solid basis for weighted fitness function design [11]. The threshold of UCC forms a transition phase of the dynamical urban behaviour that guarantees the historical sites' continuity, homogeneity and coherence, and enables embodying the fractal properties again. The research applied the novel technology to all case studies and aimed to measure the local UCC dimensions by LCFD and SLAC analyses, then calculated the mean, median, mode, maximum, minimum α and Lacunarity parameters. Finally, the research classifies all the case studies into three groups: high, medium and low in terms of their UCC level, by multivariate linear discriminant function analysis, for more detail see [11].

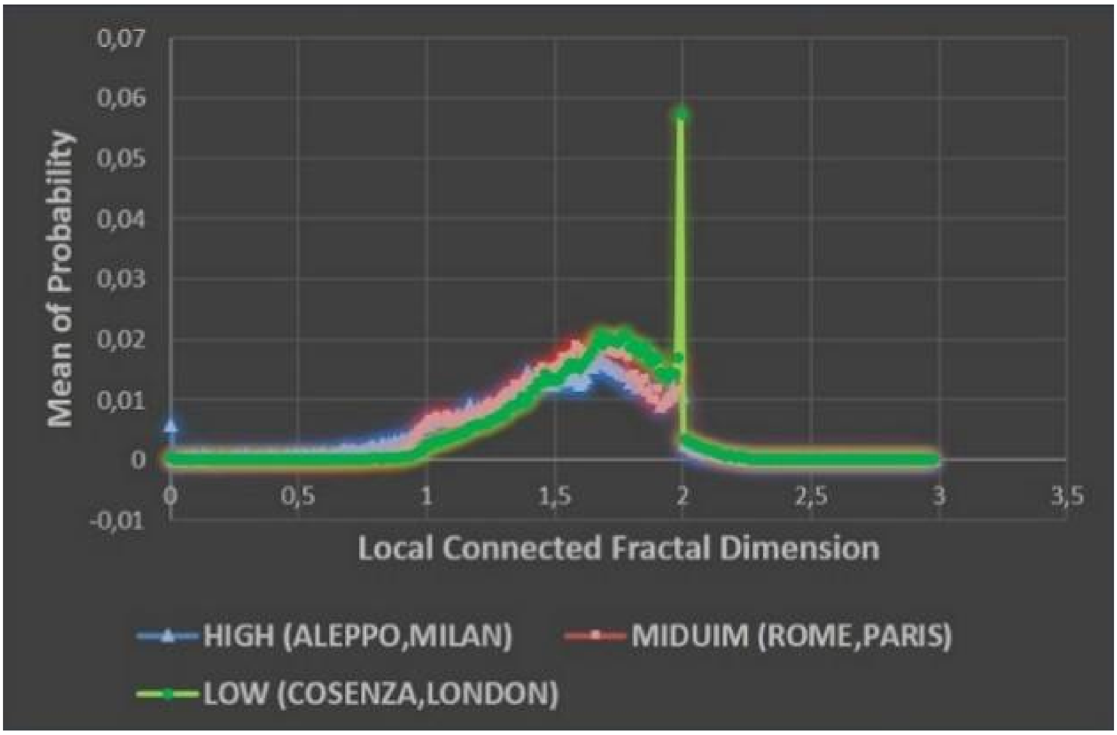

Figure 4: Mean distribution of the α value for urban Connectivity levels (high, medium and low).

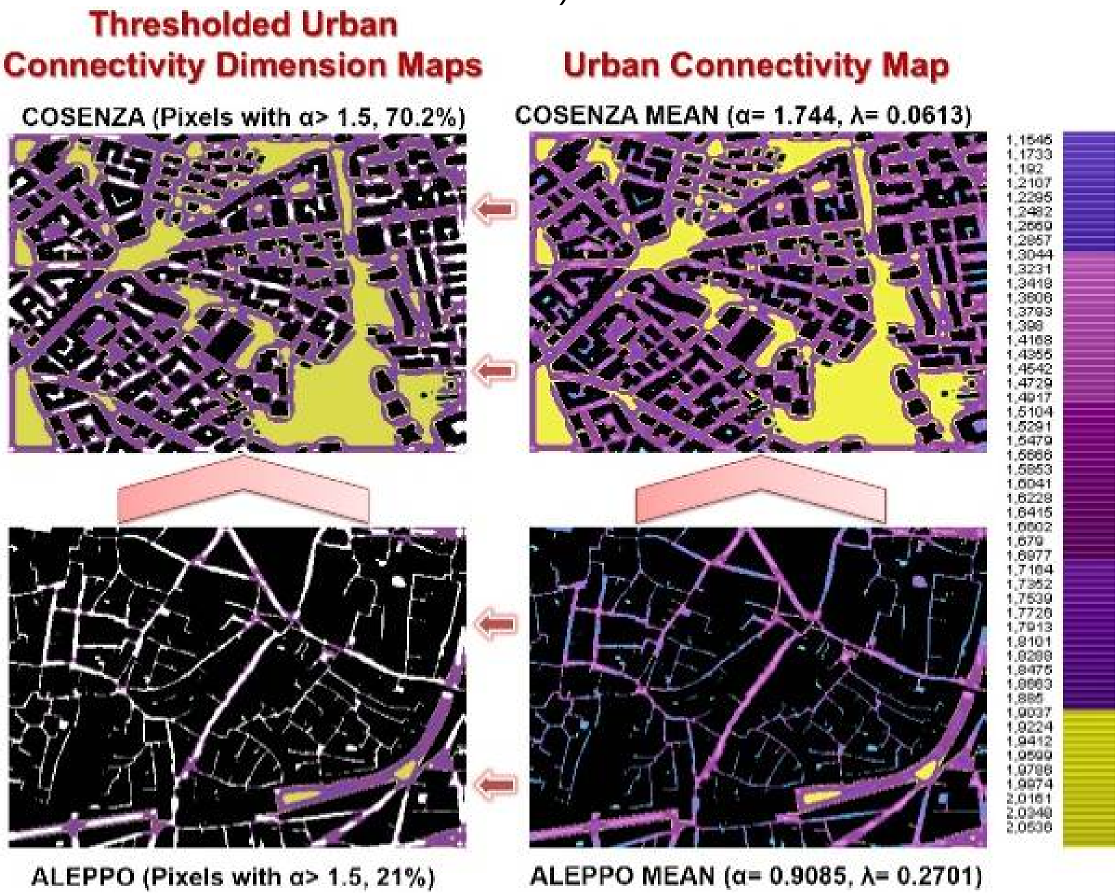

Figure 5: Urban connectivity in Cosenza and Aleppo cities and α Thresholded version of the dimensional map showing only pixels α >1.5

Where none of the variables individually allowed a useful discrimination between the two groups, Figure 1 shows the mean distribution probability in the high, medium and low connectivity level groups. Note that the urban fragmented cases, such as Cosenza city, have a higher probability of high-dimensional features (near a ~ 1.7 to 2.00 regions) with a large peak at 2 that corresponds to the areas devoid of urban interactions and connections (open spaces). Figure 2 shows the dimensional map, which, assists in interpreting the urban connectivity dimension. Where the case of low urban connectivity dimension (more fragmented areas), such as Cosenza city, possesses a considerable variation of urban network morphology (immense spatial heterogeneity), or has a high local connected dimension, with the highest rate (70%) of the Mean distribution of the αs values significantly exceed the threshold value (1.5). Whilst, the case of high urban connectivity dimension, such as Aleppo city, possesses a high stability of urban network morphology (spatial homogeneity), or has a low local connected dimension, with small rate (21%) of the Mean distribution of the αs values exceed the threshold value (1.7) [11].

In summary, the ability of SLAC to measure the heterogeneity in the urban networks represents one of the significant indicators of the urban connectivity dimension, in addition to the ability of LCFD to measure the emerged geometries' self-similarity, therefore connectivity and complexity form together the constituent components of the organism's genetic description or its genotype towards resulting its phenotype.

2.2 Filling Gaps' Approach and Parameter in the Historical Context

As natural systems typically exhibit high levels of integration between shapes, structure and material, thus, making Natures' designs highly efficient and effective forms of "computation" [14]. The research adopted a natural model of hierarchical Bio-inspired Space-filling Mechanism (BSM), which refers to specific silkworm's shape generation process and the spinning behavior of silkworms in the significant study by Oxman (2013). The main discovery (by Oxman study) showed that spinning configurations and fiber density distribution would vary according to the morphological features of the "hosting environment". Where the silkworm's filing-space mechanism has effectively adapted to the relative number and location of the available connections. Moreover, the variation in fiber density and organization reflected the morphological constraints given by the environment, also it's worth to focus on the general correlation between the fiber densities, where typically varied as a function of the distance between the central vertical axes, see figure 3-B. The research developed a new adaptive dynamical model, where the building model established on this platform had multi-parameters including the number and location of available connections (movement flows resources), number of attractors (evolved by the competition between the intersection connections' centers governed by the spatial and functional relations), for more detail see [13]. Whilst the first parameter controls geometry connectivity (social interactions) value, the second parameter controls geometry complexity (morphological self-similarity) value.

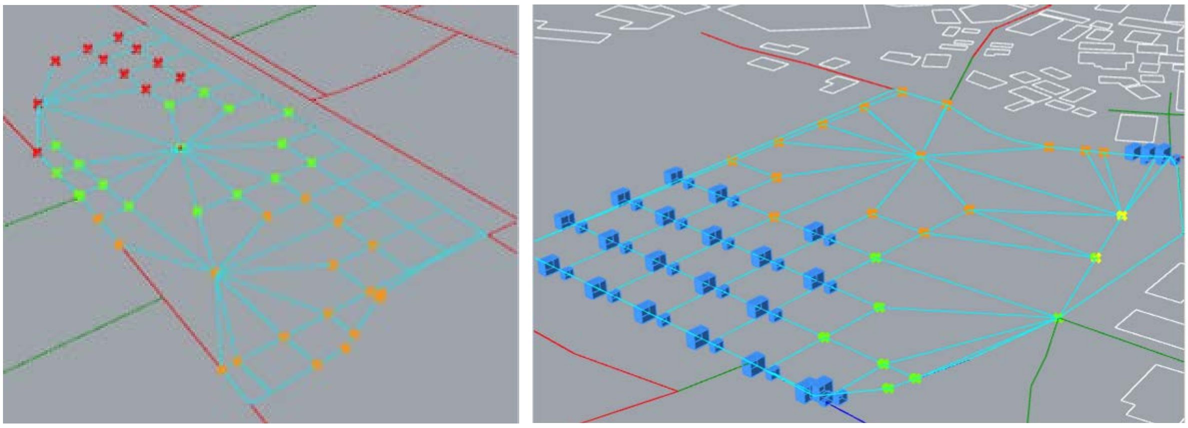

Figure 6: A) The results of attractor force algorithm of Cosenza (left) and Aleppo (right) by BSM, spatial connections in green, non-attracted centres in Blue;

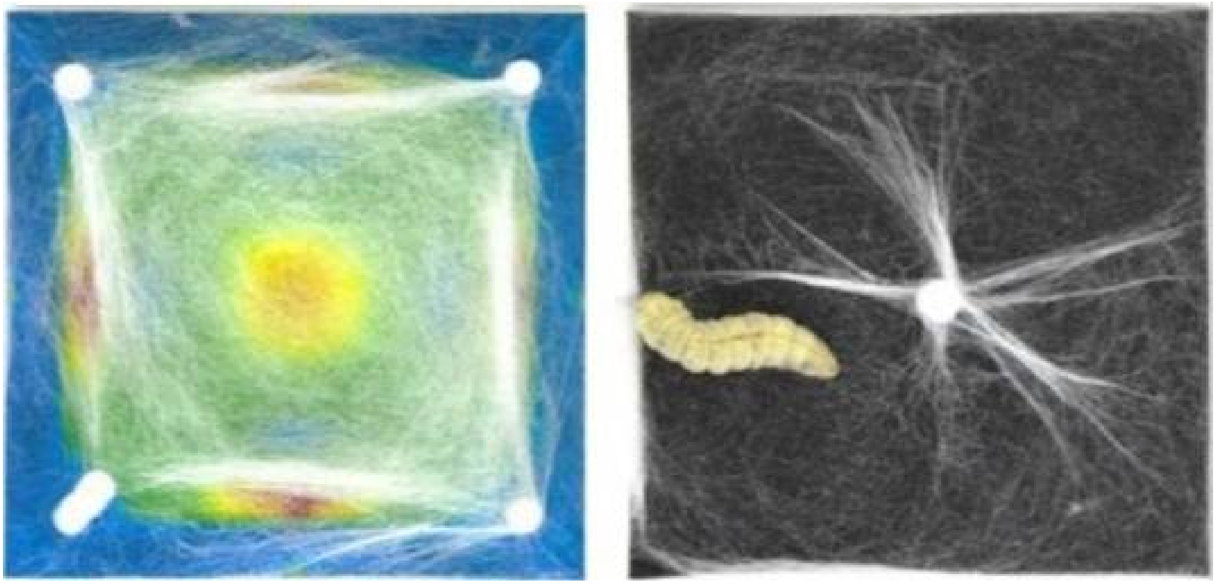

Figure 7: B) Two diverse cases of silkworm's hierarchical space-filling mechanism [14]

The hosting environment played a significant role in identifying the social and morphological features for both cases: historical city of Aleppo and Cosenza city. These features constrain the efficiency level of the BSM. Only three connections were available in the modern host environment of Cosenza case, which generated in total 119 decentralized interlinked centers and evolved three-points attractors with high force amount and large open spaces. On the contrary more than six connections were available in the historical case of Aleppo (due to the high urban connectivity dimension as seen before), which generated in total 44 centralized interlinked centers and evolved four point attractors with low force amount and small open spaces. Based on the BSM the force amount of attractor point varied as a function of the distance from the connections, where more connections (Aleppo case) give more attractor points that possess a low force amount, and vice versa, as shown in figure 3-A.

In summary, the competition between point attractors to transcend the LCFD and SLAC threshold represents the core of the self-organizing change approach. Which forms a fundamental character of a new language of form based on Multifractal design. This new form finding process incorporating with the hierarchical silkworm's shape generation process and the spinning behavior of silkworm, enables permeating and adapting with the current historical/modern phenotype and genotype successive mutations.

2.3 Generation Techniques in Spatial and Complexity Systems

According to Jencks in the new sciences and architectures, the fundamental idea relates to feedback, self-organizing change, "which the computer is well-adapted to portray” [4]. The Multifractal geometry ability to emerge self-similar structures depending on the feedback is the secret behind achieving homogeneity at spatial and functional relations. Where scaling and self-similar configuration, create complex patterns lying in planes with different orientations in a multidimensional space and subject to the approach power law scaling model [3]. So that considered the most successful approach for achieving morphogenetic outcomes that are faithful to complex adaptive systems such as a historical reality, for detail see [12]. In order to model and emerge adaptive Multifractal architecture, the research has developed a modelling software tool called Morphogenetic Fractal Architecture (MoFA). This tool constitutes from the incorporation between new Adaptive Dynamical Model (ADM) for parametric design, to model the optimization of building genotype and phenotype for seed emergence based on the local criteria “spatial and functional relations”. In this context, a number of computational approaches (field effect, point attractor and power law scaling models’) for modelling morphogenesis are compiling to study an integration.

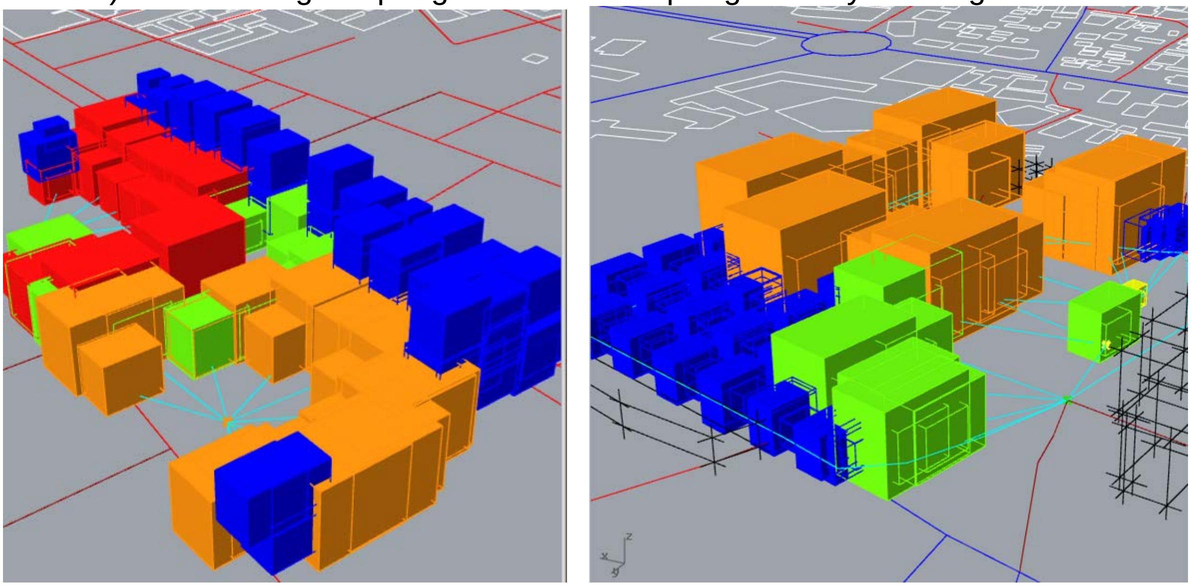

Figure 8: The results of power law scaling algorithm of Cosenza (left) and Aleppo (right) cases.

The generated geometries in Aleppo and Cosenza cases showed interacting capacity with various connections, proportional to their distance from the central attractors, which in turn, their field effect influences are proportional to each attractor proximity to the connection (movement flows resources), as shown in figure 4. Multifractal forms have been generated by controlling the correlated spatial and functional relationship characterized by high sensitive adaptability, through the capacity of responsiveness to different environment situations and changes by mutating their structure, behavior and function. Thus, generated geometries in Cosenza have high scaling values (large size) with lower spatial concentration, while generated geometries in Aleppo have low scaling-values (small size) with higher spatial concentration.

In summary, the incorporation of two models of power law scaling and point attractor proved an efficient capacity to self-organize organism’s components and define their evolution in specific stages.

3. Results

The proposed guidelines strategically aim to establish a new principle of the evolutionary design based on the major role of the socio-morphological perspectives for directing the bottom-up urban morphogenesis, by utilising a new language of forms the fractals. This principle stemmed from the significant studies of many specialist, such as Alexander (2004), Allen (2013), Batty (1994, 2007, 2013), Christaller (1933), Frankhauser (1998), Frazer (2002), Otto (2011) and Salingaros (2001), who have discussed the spatial managements, occupation, and connections at the macro level. In addition, the proposed guidelines aim to contribute and to offer suggestive evidence to the discussion of urban and geometrical forms on the microstructure, to draw a comprehensive picture with the macrostructure studies mentioned above, towards achieving a more responsive adaptable organisation, which can manage performance better.

The proposed guidelines consist of few directions possessing high capabilities to make the biggest difference in urban form behaviour and performance. These capabilities are required to learn and grow in order to improve the evolutionary process. The secret behind these capabilities is the tendency to balance contradictory forces thus enabling to manage systematically the performance of the urban interventions as a learning process through the machine learning approach, which solves the research problems by discarding the old model (Top-down).
To provide specific guidelines, addressing the socio-morphological issue, and for achieving the main objective, the research discriminates the proposed guide into few effective directions, where three directions are investigated to answer the questions of this section. This guide is expected to direct key aspects of the evolutionary design for urban morphogenesis within the historical and modern contexts. The primary directions of this guide are outlined below, where the qualitative guidelines are grouped for each direction in sub-sections under multiple design principles, which enables the stakeholders to quickly determine key design elements and criteria.

3.1 Direction 1: Definition and optimization of building genotype and phenotype

The first guideline direction addresses two key principles for the evolutionary design to create building genotype and phenotype: the genetic description and the attractor force, as shown in Tables 1, 2.

Table 1: The First Key Principle, Genetic Description

GENETIC DESCRIPTION (PRINCIPLE 1.1)

WHY THIS IS IMPORTANT	Successful identification of the constituent components of the organism's genetic description (or its genotype) solves the dilemma of initiating self-optimisation process.
GUIDELINES	▪ Select the quadratic grid as the most adaptable spatial network, which could easily transit to another grid and allows any form of division and any form of occupation.
	▪ Provide and generate all the available movement flows to find how to occupy the urban gaps with the optimal attractor or repeller centres.

	▪ Design a balanced network system, respects the current spatial configuration, possesses a quick orientation within the system and freedom of division, and achieves efficient occupation.

Table 2: The Second Key Principle, Attractor Force

ATTRACTOR FORCE (PRINCIPLE 1.2)	
WHY THIS IS IMPORTANT	An objective assessment of the relationship between the elements that constitute the genotype; and a correct weighing and calculating of the attractor force guarantees achieving a homogeneity phenotype.
GUIDELINES	▪ Develop a minimal path between attractors or repellers governed by the local criteria (see principle 1.1) and the global criteria (fitness function design), to be influenced by the generated field force. ▪ Compute the inherent strength from each movement flow and then merge all the created fields into centres (as attractors or repeller). Merging is based on the proximity from the attractor or repeller and the force of the attractor or repeller itself (see principle 1.1). ▪ Weighing and balancing the multiple forces then provides each attracted point with the crucial inherited instructions.

3.2 Direction 2: Filling gaps approach and parameter in the historical and modern contexts

The second guideline direction addresses two key principles for the evolutionary design to find the appropriate space occupation mechanism, and architecture forms: bio-inspired filling gaps technique and adaptive architecture form, as shown in Tables 3, 4.

Table 3: The Third Key Principle, Bio-inspired Filling Gaps Technique

BIO-INSPIRED FILLING GAPS TECHNIQUE (PRINCIPLE 2.1)	
WHY THIS IS IMPORTANT	Finding the appropriate space-filling mechanism to fill the urban gaps is a pivotal step towards generating harmonised and cohesiveness exploratory geometries enhance the current complexity through morphological and social behaviour.
GUIDELINES	▪ Look for the analogy between an evolutionary model of nature and the generating process for architectural form. Then determine a natural (Biological) system that exhibits high levels of integration between three constraints shape, structure, and material. ▪ Translate the natural space-filling mechanism into a bio-inspired method, in terms of the symbiotic behaviour and metabolic balance. ▪ Embody the bio-inspired method by generating a self-reproducing system at each attractor point (see principle 1.2).

Table 4: The Fourth Key Principle, Architecture Form

ADAPTIVE ARCHITECTURE FORM (PRINCIPLE 2.2)	
WHY THIS IS IMPORTANT	An adaptive architecture form characterised by high sensitive adaptability, through the capacity of responsiveness to a different environment is the missing link to control the correlated spatial and functional relationships.
GUIDELINES	▪ Select the attractor of every attracted points group as scaling centre for each self-reproducer group. ▪ Design a weighted process for calculating the golden scaling factor for each self-reproducer based on its field effect and the host environment influences. ▪ Generate multifractal geometries by scaling the attracted points according to their golden factor and utilise self-similar configuration governed by the attractor force (see principle 1.2).

3.3 Direction 3: Urban generation techniques in spatial and complexity systems

The third guideline direction addresses two key principles for the evolutionary design to develop weighted fitness function, and let nonlinear Multifractal architecture emerge, as shown in Tables 5, 6.

Table 5: The Fifth Key Principle, Weighted Fitness Function

WEIGHTED FITNESS FUNCTION (PRINCIPLE 3.1)	
WHY THIS IS IMPORTANT	Applying weighted fitness function design formulates a crucial progress toward joining interactive approaches in the field of multiple criteria decision making with the set-based approach pursued in the evolutionary multi-criteria optimization field.
GUIDELINES	▪ Design a loopy process for identifying the stop criterion of the optimisation phase, harmonises with the current development value of the urban connectivity and self-similarity. ▪ Enable the designer to modify the stop criterion during the optimisation phase, according to the need of revaluing the urban connectivity and complexity or reduced it. ▪ Validate the performance, hierarchy, and coherence of the exploratory prototyping, by verifying achieve the development threshold.

Table 6: The Sixth Key Principle, Non-linear Multifractal Architecture

NONLINEAR MULTIFRACTAL ARCHITECTURE (PRINCIPLE 3.2)	
WHY THIS IS IMPORTANT	Emerging nonlinear Multifractal architecture means to allow for achieving harmony, homogeneity, and coherence of a nonlinear feedback system by involving the approach of scientific complexity.
GUIDELINES	▪ Adopt the values of urban connectivity and complexity threshold (see principle 3.1) as

global criteria, to guarantee to embody the fractal properties again in the historical and modern contexts.

- Ask the self-reproducing systems to change their structure and behaviour through the interplay between the genetic code (complexity and connectivity values) and its interactions with other population until transcend the threshold values.
- Apply the technique of evolutionary multi-criteria optimisation for solving the contradictory objectives and then select the optimum solution based on the feedback of the host environment and its reaction to the exploratory prototyping.

5. Discussion and Conclusion

Verification of research hypotheses and responding the core questions, are verified due to adopting creative architecture and urban concept depending on the convergence of scientific complexity approach and artificial intelligence on the one hand, with the complexity approach of architecture and urban morphology, on the other hand.

In addition to the main guidelines that derived from the previous parts, the next points could form significant conclusions:

A. The parameters of connectivity and complexity values form the core of weighted fitness function design, which catalyst the designer to play a powerful role in a digital evolutionary design for achieving hybrid control of the optimization criterion between the designer and evolutionary processes.

B. According to the biomimetic objective, Multifractal forms have been generated by controlling the correlated spatial and functional relationship characterized by high sensitive adaptability, through the capacity of responsiveness to different environment situations and changes by mutating their structure, behaviour and function.

C. Living organisms (such as cities) are using specific rules for evolution or mutation because all organisms appear to be organized by internal attractors. Therefore, all organisms and architecture must show some self-similarity and be subjected to the influence of point attractor model, because it brings the system to a stable state. So that living organism, which started their evolutionary chaotically ended with deterministic chaos behaviour mixture.

D. The learned lessons that urban morphogenesis and architecture typologies should be aware of: approaching power law scaling model is the most successful approach to achieving morphogenetic outcomes that are faithful to complex adaptive systems such as historical one. In particular, when accompanied by fractal language, which could absorb such heterogeneous material from nature and culture.

E. This ADM represents a tipping point in computational and parametric architecture design, towards achieving a practical application and unifying the scientific complexity with architecture approaches for addressing the problem. The powerful emergence ability of this creative model derived from the pivotal role of Multifractal self-organizing process in achieving harmony, homogeneity, and coherence in the historical context. Despite that, presented results are not very realistic since there are more approaches and perspectives that need to be involved.

Finally, the focus on design (filling/renovate empty or destructive gaps) in adaptive complex systems such as the historical ones has an imperative need to be shifted from the design of the form to the design of the processes of development of those forms or their morphogenesis. Where Peterlin argued that, instead of describing the form, designs could describe the components (results of self-organized processes) and the relations between them, and the rules defining their development in specific stages [15]. Thus, shifting to processes might benefit design's adaptability and variability.

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