GAs and Evolutionary Design in Architectural Heritage-The Case of Islamic Architecture

Osama Mohammad Alrawi

Associate Professor of Architecture, Department
of Architectural Engineering, Faculty of Engineering and Technology,
Future University,Cairo Egypt
pleximotif@yahoo.com

Abstract. The cosmological nature of Islamic architecture makes it a useful case study for the capability of the adaptation, assimilation and accommodation with the development of evolutionary algorithms and their applications in architectural design. Genetic algorithm derives its structure from the observation of nature. Since algorithmic art consists of generation of images on the basis of algorithms, algorithms can be viewed as a notation, and notation is something that music has but visual artifacts in general miss. This paper aims to discover the role of evolutionary algorithms in historical Islamic architecture. Also, we shall try to investigate the way in which the future development could occur not only through the discovery of new facts or theories, but also through the rise and dissemination of new visions having different explanation of Islamic architecture that considers it as a result of serious application of formation through evolutionary genetic algorithm.

Keywords: Genetic algorithms, Architectural heritage, algorithmic art, Islamic Architecture, Generative and parametric design.

1 Introduction

In nature, evolution is mostly determined by natural selection or different individuals competing for resources in the environment. Evolutionary algorithms are ubiquitous nowadays, having been successfully applied to numerous problems from different domains, including optimization, automatic programming, machine learning, operations research, bioinformatics, and social systems (Bladowski, 2011).

Usually grouped under the term evolutionary computation or evolutionary algorithms, we find the domains of genetic algorithms, evolution strategies, evolutionary programming and genetic programming (Fig. 1 The main domain of Genetic Algorithms). They all share a common conceptual base of simulating the evolution of individual structures via processes of selection, mutation, and reproduction (Ajith, 2010). Emergence refers to the universal way in which small parts of systems in nature driven by very simple behaviors are tended toward coherent organizations with their own distinctly different behaviors (Fasoulaki, 2012). Vivid examples from the natural world are the hive, swarming, and flocking where independent parts are formed into

M. Ioannides et al. (Eds.): EuroMed 2014, LNCS 8740, pp. 507–516, 2014.

one system with a complex or / and random behavior. It is with cosmic evolution, with such inanimate things such as crystals, solar systems and galaxies. Cosmic and natural evolutions are the growth in complexity (Jencks, 2007).

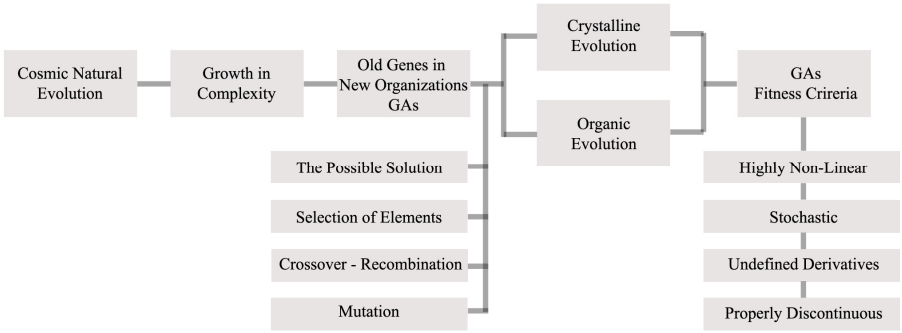


Fig. 1. The main domain of Genetic Algorithms (*source: author*).

2 Islamic Architecture and the Emergence of Evolutionary Algorithms

Emergence is the creation of new organization that arises through the development of new relationships of control and constraint. The key to appraising increasing organization is to distinguish between "complicated" and "complex" systems. As a system becomes more complicated in order to solve local problems, there is no increase in flux or organization, but rather the adding of new parts that are the same with old parts. Increasing complexity, though, results in the elaboration of organization rather than the elaboration of just structure. In other words, complex systems are *rich in organization*, while complicated systems are *rich in detail* (Fig. 2 Evolution and Emergence in Islamic Architecture).

Genetic Algorithms (GAs), a computational technique based on the principles of evolution, have been recently introduced in architecture to address problems of complexity in the function and the form of architectural projects. While there has been an increasing interest in the use of GAs in architecture, there has not yet been a systematic study of the operation of GAs and their application in architecture yet (Fasoulaki, 2012). Like other computational systems inspired by natural systems, GAs have been used in two ways: as techniques to solve technological problems and as simplified scientific models that can answer questions about nature.

Emergence refers to the universal way in which small parts of systems in nature driven by very simple behaviors are tended toward coherent organizations with their own distinctly different behaviors. The term of Emergence equates architecture with nature assuming that design is dominated by the same principles as the natural world. Architects attempt to create architecture as nature; architecture that is nature. That is why the notion of emergence is linked tightly with the notion of growth, evolution, continuity and behavior.

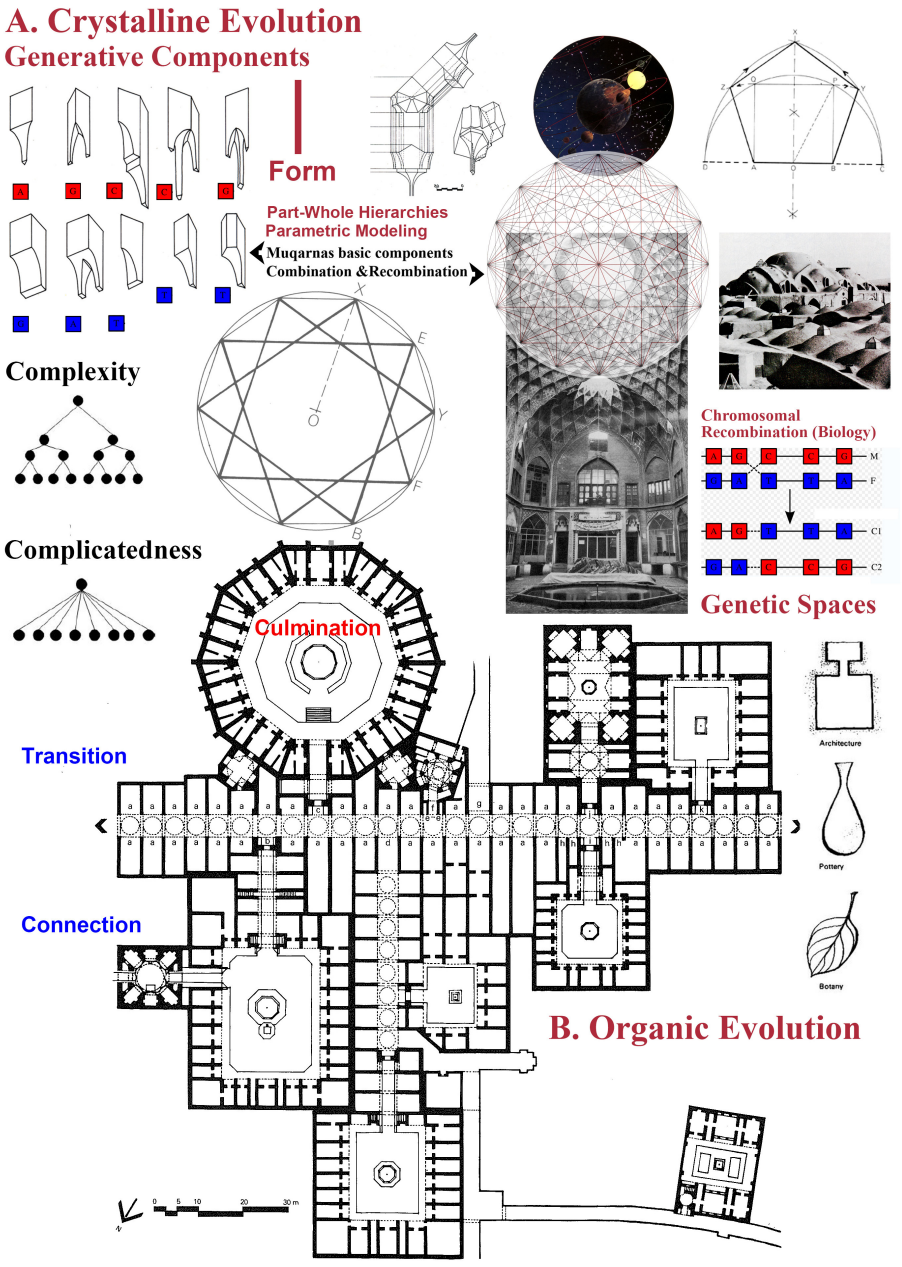


Fig. 2. Evolution and Emergence in Islamic Architecture (*source: author*)

Complexity is created, in part, by nature using old genes in new organizational ways. Because of physical laws such as gravity, and the tendency for them to make all matter self-organize, the universe displays ever-increasing organization. On earth such self-organization precedes organic evolution by billions of years, and it operates according to different laws than natural selection. This could be called *crystallized evolution*: the tendency of all material systems, given the input of continuous free energy, to develop towards more crystalized or defined states. *Organic evolution*, like the crystalline variety, also has a general direction towards greater complexity and it is not only propelled by the same self-organizing forces but also by natural selection (Fig. 2 Evolution and Emergence in Islamic Architecture). Thus the two types of evolution, crystalline and natural, combine to produce more highly organized systems and individuals. This is the main plot of the universe story, but it is a progressive drama that encounters many setbacks (Jencks, 2007).

In Islamic architecture and urbanism space is also structured. In structured space, man knows where he is; direction is meaningful to him. Reinforcing this universal order are the corporeal creations of the macrocosm and the microcosm which exhibit with its strong emphasis on the family unit, provide an important sociological reinforcement for the centripetal organization of space and space usage (Ardalan, 1973). Design lives within two fundamental stages, the creative and the evolutionary. The *first* is that of producing the idea: this approach is built activating a logical jump between the existing and possible worlds that represent our wishes and thoughts. The *second* is the evolutionary stage, that of the development of the idea. This approach runs inside paths of refinement and increases in complexity of the projects. It involves the management of the project to reach the desired quality (Randly, 2004). The architecture of traditional cultures demonstrates that it was the social constrains that conditioned the traditional urban form, backed up by shared values and correlated social conventions (Bianca, 2000).

Most optimization problems are made up of three basic components (Fig. 3 Elements of Genetic Algorithms). The *first* is the objective function which we want to minimize or maximize, the *second* component is the designation of a set of design variables that affect the value of the objective function, and the *third* component is the determination of a set of constraints that allow the design variables to have certain values (Fasoulaki, 2012). In this regard we could refer to Genetic algorithms (GAs) that forms randomized search and optimization techniques guided by the principles of evolution and natural genetics, having a large amount of implicit parallelism. Even though there is no formal definition of GAs, all of them consist of four elements. *The first* is the population of chromosomes which represent the possible solutions of the problem. *The second* is the Selection of element and it refers to the part of the population that will evolve to the next generation. Selection is performed based on a fitness function that determines how "good" a solution is. The selection process is applied to each generation produced. *The Third:* Crossover (also called recombination), refers to the combination or exchange of characteristics between two members of the elite group defined by selection, by which offspring is produced. *The forth, Mutation,* in any case, before re-applying selection to the new population, mutation takes place. Mutation is a random event, occurring with a user-defined probability to only some of the new offspring. It is used to maintain genetic diversity by altering only a little piece of the new offspring.

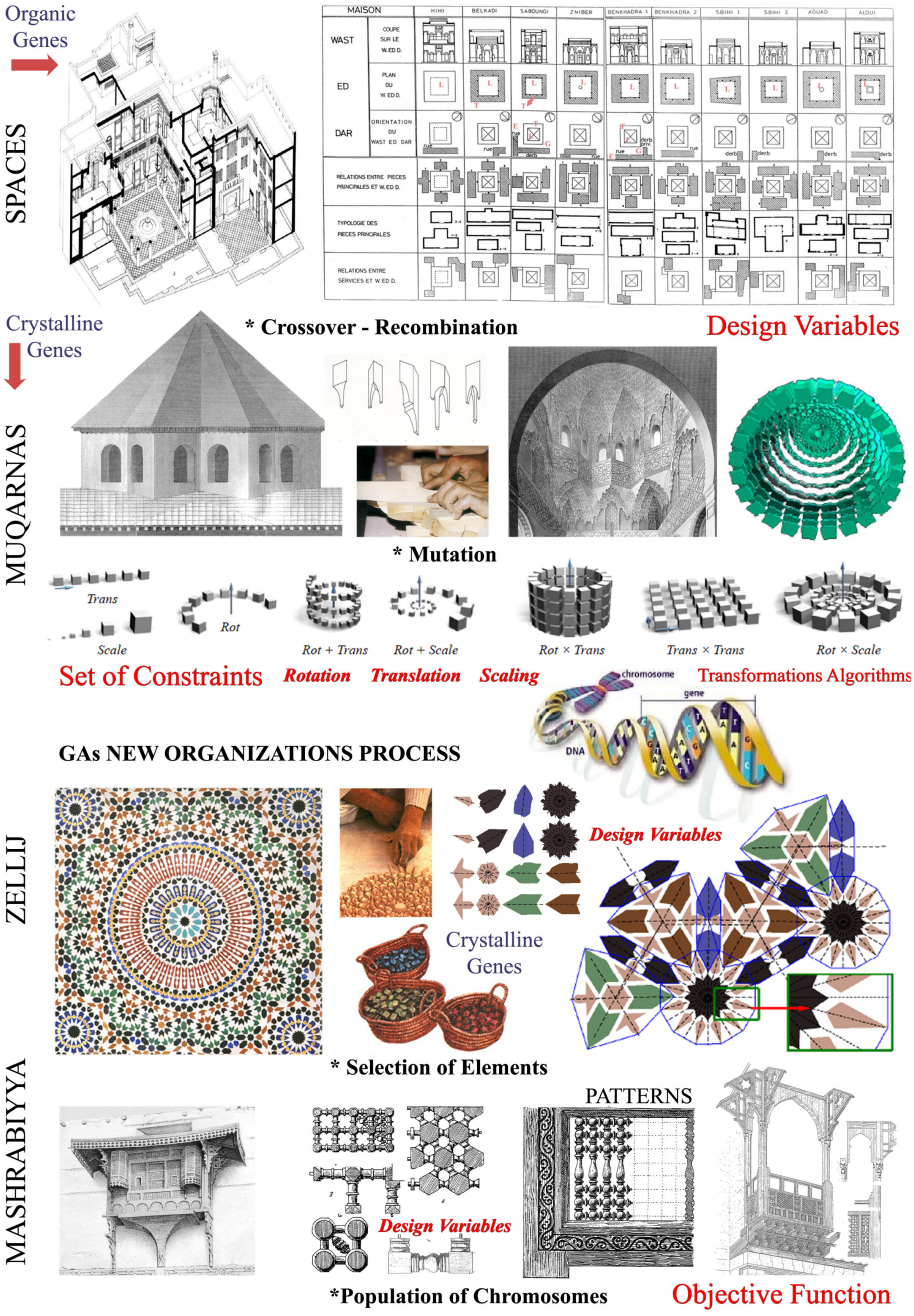


Fig. 3. Elements of Genetic Algorithms in Islamic Architecture (*source: author*)

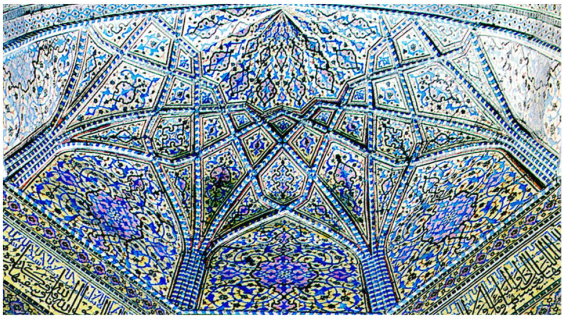
3 The Genetic Algorithms Fitness Criteria

Genetic algorithms provide a useful commencing framework since they already have a formal representation of various constructs and the combination and mutation operators (Gero, 2006). In architecture, form elements are architectural vocabularies that are simply some small, usually carefully chosen subset of the structures handled by some basic design system. Traditionally, architectural elements are walls, doors, columns, floors, rooms, windows, arches, ornaments, etc. Columns, beams and wall panels are elements of construction, and rooms are elements of spatial composition. Architectural buildings are composed of those elements. Repetition of the same types of those elements in a group of objects characterizes a style. For example, ribbed vaults repeatedly appear in most Islamic architecture especially in Iran and Uzbekistan. Variables of abstract shape patterns can be instantiated into shapes or patterns. In analogical reasoning, shape pattern schemas learned from one domain can be instantiated or applied in different domains. There are many possible generation methods, including instantiation, analogical reasoning, shape grammar and genetic algorithm (Fig. 4 Objective functions of Genetic Algorithms).

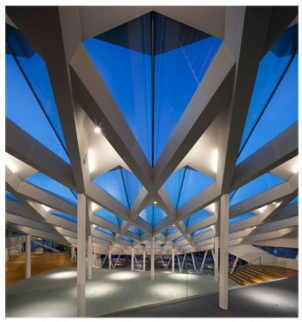
Genetic Algorithms are best used when the objective function is: *First*, highly nonlinear; a nonlinear system is one whose output is not directly proportional to its input. *Second*, stochastic; a stochastic process is one whose behaviour is non-deterministic; it can be thought of as a sequence of random variables. Any system or process that can be analysed using probability theory is stochastic. *Third*, has undefined derivatives; the derivative of a function represents an infinitesimal change in the function with respect to one of its variables. Loosely speaking, a derivative can be thought of as how much one quantity is changing in response to changes in some other quantity, and *finally*, properly discontinuous, as subgroups contains a number of a component that also contains a discrete subgroup of basic elements, after an appropriate choice of a base form.

Since form in architecture is a cultural artifact, imaging numerous abstract meanings as previously mentioned, form cannot be subjected to the Darwinian definition of evolution. Architects must clarify where architecture is literally considered as part of nature, where there are analogies or metaphors, and where nature is a source of inspiration.

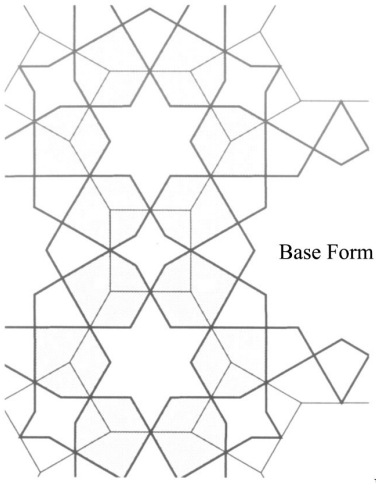
There is no doubt that abstract shapes of a conceptual world may be implemented in the future, opening the path for new formal expressions. However, the real challenge would be to use GAs in real-world architectural contexts. Indeed, it is very difficult for a designer to combine complexity and constraints imposed by the design problem with evolutionary formal generation. Possibly this is the reason why architects use GAs either as a tool to solve structural and mechanical problems or as a tool to generate forms (Fasoulaki, 2012). Some structures in Islamic architecture when compared with some recent structures were able to develop algorithms which were able to optimize a three-dimensional pin joint space frame under the application of dynamic forces by using a genetic algorithm. The algorithm itself was based on a bottom-up approach as there was no specific direction for the end topological result but the structure was rather established on the study of its local properties. The relationship of the finite point elements called particles which compose the structure characterizes the overall outcome.



A. The Madrasa-Masjid of Tilla Kari,
Bukhara, Uzbekistan,1647

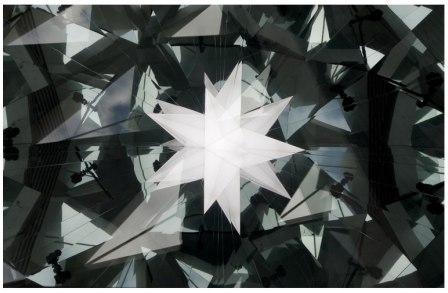


B. Middelfart Savings Bank / 3XN
Architects: 3XN
Location: Middelfart, Denmark
Project Year: 2010



Base Form

Pre-fabricated
ceiling units



Layout

Fig. 4. The main domain of Genetic Algorithms (*source: author*)

4 Time Fixed vs. Timeless Architecture

The universe has a tendency to be interesting, and grow ever more so with time. Quality, superior organization and increasing sensitivity are built into the direction of the universe (Fig. 5 Growth and development in nature and architecture). There is the internal, spiral staircase of development towards more complexity. Today there is unusual mixture of science and visual languages, or design codes based on the myriad patterns of organization that the fundamental laws generate. The computer is particularly adept at revealing these patterns of nature, the fractals, strange attractors, complex morphological shapes of folding, and close packing.

This leads to architectural language that stems from structural or ornamental parameters and curved morphologies, complex elements that are often best explored through digitization. Qualities emerge from relationships between elements, or relationships

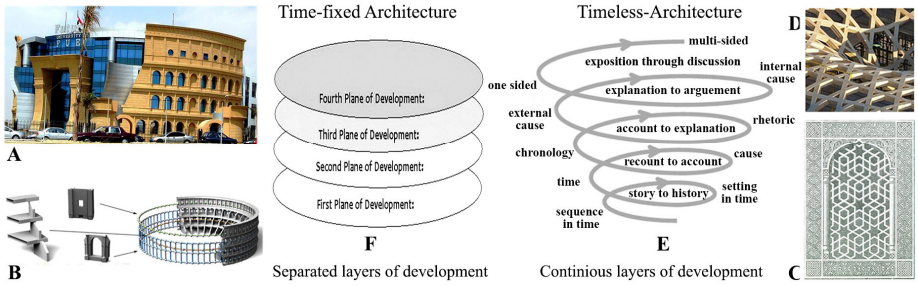


Fig. 5. Growth and development in nature and architecture. A-Future University in Egypt, B-Roman Coliseum, C- Geometric Patter of a window in Qalawun Masjid in Egypt, D- Timber construction for the Yeoju Golf Club by Shigeru Ban: CAD/CAM by design to production. Reference: Geodesic Pattern, H. Pottmann. E- The growing spiral of development (Timeless-Architecture). F- The constant-static layers of development (Time-fixed Architecture) - (source: author).

between these relationships. Form relationships are a kind of syntax or compositional patterns that can be analysed and expressed formally. Genetic algorithms can use learned shapes and shape patterns as genotypes or phenotypes. Using genetic algorithms, many shape *patterns* can be produced (Myung, 2009).

Islamic Art and architecture, constrained, or maybe underpinned by the aniconic approach, concentrates on *geometric pattern* and draws attention away from the representational world to one pure form and meaning. To trace this in creation the direction is not backward but inwards (Critchlow, 1976).

Islamic Architecture proved to be engaged at early stages in the history of architecture to use design methodologies that designers and researchers lately turned for inspiration to nature and its morphogenetic rules in order to improve the performance of their designs and introduced thus a new term for architecture. The so-called Evolutionary Architecture refers to the exploration of the form-generating processes, paralleling a wider scientific search for a theory of morphogenesis in the natural world. Architectural concepts were not only the representation of shapes and forms but rather a set of generative rules whose evolvement leads to the formation of space. Within the hierarchy of spatial definition, shapes are delimited by their surfaces.

The fact that Islamic art was seen as purely decorative surfaces would bewilder to argue that the source of these “patterns” was indeed natural in that they explore the natural and cosmic order, and are also reflections of the timeless truth of unity. The principle of unity brought into being an aniconic art in which the spiritual world was reflected in the sensible world not through iconic forms but through arabesque, muqarnas and rhythm (*time*). Islamic artists appropriated key elements from the classical tradition, and then elaborated upon them to invent a new form of decoration that stressed the importance of unity, logic, and order. Essential to this unique style were the contributions made by Islamic mathematicians, astronomers, and other scientists, whose ideas and technical advances are indirectly reflected in the artistic tradition.

Style, recognized from the same form elements, is regarded as a part of the knowledge structure about objects; therefore it is represented by a set of elements composed of sub elements and their relationships which are embedded into a knowledge structure. Distinct and replicate syntax or compositional patterns in a set of objects, which can be analyzed formally, characterize style (Myung, 2009). The structural view of style is that style is about relationships, rather than simple features. Relationships are the way elements are organized. Knowledge of an object can be represented with elements and their relationships in hierarchical structures.

Generalization rules such as dropping condition rule, turning constants into variables rule, climbing generalization tree rule, are elaborated using shape pattern representations and generalized shape pattern descriptions are produced as style knowledge that characterize the set of shape objects.

That knowledge is design knowledge such as spatial relationships or patterns that cannot be easily recognized in terms of physical properties. The integration of prototype and family style can produce various shape objects that are regarded as members of a class to which a previous shape belonged. Learned style descriptions provide important design knowledge for generation processes, such as instantiation, parametric design, analogical design, metaphor design, generative shape grammar and genetic algorithm. The processes described give the computer the ability to learn design knowledge, for supporting design computation and creative design by either humans or computers (Myung, 2009).

5 Conclusion

Evolutionary Design in Islamic architecture is the result of a comprehensive ideological system that is based on the axiom of choice and the well ordering principles of creativity and creation. Deep analysis for this architectural heritage, proved the use of tools and techniques of evolutionary genetic algorithms regardless using this terminology in the history of this type of architecture. The reason for that is the cosmological nature of this architecture which was ideologically oriented toward the laws of nature which God had created in his universe. The laws of nature turn out to be universal (apply everywhere in the universe), absolute (do not depend on anything else), eternal (do not change with time), omnipotent (all-powerful), and creative (cosmogenetic). Primitive analogies are found at several levels between cosmic and human processes. In Islamic architecture, both spaces and archetypes are genetic, parametric and generative, to be in this manner compatible with the universe that grows in complexity and also offspring that growth in culture. This experience existed in the comprehensive and integrated design methodology through its different levels, starting with urban spaces and ending with the architectural details. At different levels of reality, the universe is becoming the measure of all things and is wrapped in daily life. Cosmo genesis is the metaphorical web that penetrates every area of life and matter, tying them together in a partly finished architecture.

Changes in Islamic Architecture and its future development need to use the tools and techniques of evolutionary algorithms as means to the rediscovery of God's reve-

lations. Islamic Architecture within this context contains the means to enable man to see the forms of nature once again as a source of inspiration and multiplicity as so many reflections of the Unity which is both the origin and end of the order of multiplicity. Due to evolutionary algorithmic system that was proved to be resident in the core formation of Islamic art, architecture and urbanism, it is of great importance for future research to capture the patterns of these algorithms and treat them as a starting point to preserve the identity and character of modern Islamic cities.

In historical Islamic cities, form results from the delimitation of structured space. Numbers are the units of this spatial definition, and geometry expresses the “personality" of these numbers. Through the use of numbers and geometry, as mathematical expressions, the creation of shapes recalls the Archetypes.

References

1. Agoston, E., Eiben, R.H., Zbigniew, M.: Parameter Control in Evolutionary Algorithms (2011)
2. Ajith, A., Nadia, N., Luiza de Macedo, M.: Evolutionary Computation, from Genetic Algorithms to Genetic Programming. Department of System Engineering and Computation, Engineering Faculty, State University of Rio de Janeiro (2010)
3. Ardalan, N., Bakhitar, L.: The Sense of Unity- The sufi tradition in Persian architecture. Chicago, USA (1973)
4. Bianca, S.: Urban Form in the Arab World past and present. Thames and Hudson, UK (2000)
5. Bladowski, J.: Algorithmic architecture. Gdańsk University of Technology (2011), http://nas.isep.pw.edu.pl/kok/journal/index.php/archive-issue/volume-2-year-2011-issue-1-january-march/file/20-algorithmic-architecture
6. Critchlow, K.: Islamic Patterns: an analytic and cosmological approach. Thames and Hudson, New York (1976)
7. Fasoulaki, E.: Genetic Algorithms in Architecture, a Necessity or a Trend. Department of Architecture, Massachusetts Institute of Technology (2012)
8. Francisco, A.G., José, M.G., Manuel, P.: Reconstruction Techniques for Image Analysis of Ancient Islamic Mosaics. The International Journal of Virtual Reality 8(3), 5–12 (2009)
9. Gero, J.S.: Key Centre of Design Computing. Department of Architecture and Design Science, University of Sydney, NSW, Australia (2006)
10. Jencks, C.: Critical Modernism, Where is Post-modernism Going? Wiley Academy, Great Britain (2007)
11. Myung, Y.C.: Style Learning - Inductive Generalisation of Architectural Shape Patterns. Department of Architecture, Paichai University, Taijon Seogu Domadong 439-6, South Korea (2009)
12. Papapavlou, A.: Structural Evolution - A genetic algorithm method to generate structurally optimal delaunay triangulated space frames for dynamic loads. Bartlett School of Graduate Studies, University College of London (September 2008)
13. Randly, L.H., Sue, E.H.: Practical Genetic Algorithms, 2nd edn. Wiley, NJ (2004)
14. Ujjwal, M., Sanghamitra, B.: Genetic algorithm-based clustering technique. Department of Computer Science, Government Engineering College, Kalyani, Nadia, India (1999)