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Some Examples on the 'Evolutionary &Genetic', and 'Artificial Life' Strategies in Architectural Design

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ABSTRACT: *Branches of soft computing emerged before the 1990s, but soft computing became an independent new discipline after the 1990s. Since then, soft computing became one of the top research areas in AI studies. Unlike other computing techniques, soft computing strategies are more tolerant to imprecision, uncertainty, probabilities, predictions, approximations. This technique has started to be used widely in a wide range of disciplines because it can quickly deal with solution sets, optimisation of solutions. Soft computing strategies generally take the human mind as a role model in architectural design. This article discusses some examples in the architectural design that consider the evolutionary & genetic, and parametric strategies. The primary method of the article bases on qualitative analysis, which is shaped by theoretical reading and explanation.*

KEYWORDS- *architectural design, evolutionary and genetic strategies, parametric models*

I. INTRODUCTION

The techniques that benefitted from the matters related to evolution, genetics and biology in soft computing field is Evolutionary Computing. The main logic in evolutionary computing, especially in generating new algorithms, is imitating strategies emerging in natural evolution to create better or optimised solutions. Scientists in this field took advantage of Darwin's theory of survival of the fittest. Evolutionary algorithms are created from crossing over fittest individuals genes in random solution sets for the given problem through artificial selection. Taking natural selection as an example and system, then randomly selects some of the newly generated solutions and tries to add new characteristics to them through a process known as mutation. In these systems, the fitness degree of the solution can be measured by a function known as the fitness function. The basic logic of these systems is to improve solution quality by creating newer and newer generations similar to natural evolution [1]. In evolutionary computing strategies, as well as genetic algorithms, there are different strategies used by experts. We would mentioned them as swarm intelligence strategies (ant colony optimisation, artificial bee colony algorithm, bees algorithm, particle swarm optimisation), evolutionary strategies (dual-phase evolution, evolutionary programming, differential evolution, genetic programming, gene expression programming, cultural algorithms), artificial life (digital organism, artificial immune system). One of the most prolific contributions to computer-aided architectural design has been made by the sub-fields of them among the other soft computing areas.

II. EVOLUTIONARY & GENETIC STRATEGIES IN ARCHITECTURAL DESIGN

The evolutionary strategies in computer media usually benefit from techniques generated from biological issues related to adaptation, evolution, and genetics for solution optimisation, complexity and randomness, and machine learning. Most evolutionary computing strategies generally based on genetic algorithms. Genetic algorithms can be described as adaptive heuristic search algorithm based on the evolutionary ideas of natural selection and genetics, especially Darwin's law as survival of the fittest. They represent an intelligent exploitation of a random search used to solve optimisation problems which means they deal with historical information to better research the research domain[2]. Genetic Algorithms generally includes four elements: the population of chromosomes representing the possible solution of the problem, selection symbolising evolving population to the next generation and fulfilled through fitness function assessing the quality of solution, crossover ascribing the combination of exchanging codes. After this three-step process completed, the following code generations emerge. The fourth element of genetic algorithms is mutation used for maintaining genetic diversity by altering only a little piece of the new offspring. Genetic Algorithms are heavily used for solving the nature of the problem, finding domain including solutions, encoding solutions. They are one of the most used algorithms for optimisation. The more complexity degree of genetic algorithms increased, then the more difficult problems could be solved,because the more complex systems are needed in genetic algorithms [3].

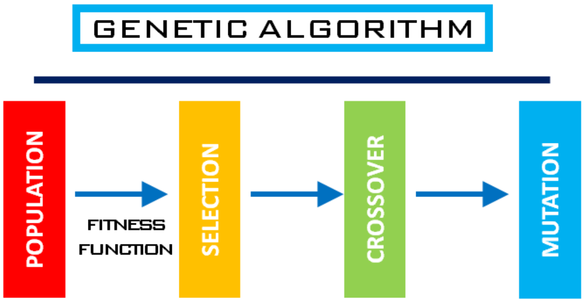

Figure 1 The figure shows the operant of genetic algorithms designed bythe Authors. The ideas of [4] adopted here.

One of the first attempts in applying genetic algorithms to architectural design was made by John Frazer in his book 'Evolutionary Architecture' in 1995 [5]. After Frazer, some architectural theoreticians such as Neil Leach, Manuel De Landa, Kostas Terzidis, Peter J. Bentley, David W. Corne, Ernst Mayr examined the potentials and results of the implementation of genetic algorithms to the realm of architecture. Genetic Algorithms generally applied to architectural design problems related to the form, function, or performance of building to find optimised solutions. One of the most used techniques in architectural design within soft computing is based on genetic algorithms. Commonly, genetic algorithms are used in architecture for form-finding and optimisation. In optimising architectural design problems, Genetic Algorithms address well-defined building problems, such as structural, mechanical, thermal and lighting performance. In the form-generations, Genetic Algorithms are used under the scope of the concept of emergence. However, compared with science, genetic algorithms cannot be broadly applied to architectural design due to the nature of architectural design as an ill-defined and very complicated, polyvalent structure. In the optimisation process, genetic algorithms deal with three components of problem optimisation. The first one is the objective function, which we want to minimise or maximise; the second one is the designation of a set of design variables affecting the value of the objective function. The latest one is determining a set of constraints, letting the design variables have specific values. Optimisation generally implemented to these issues; cost estimation, structural, acoustic, lighting, energy and spatial attributes/properties of a building [6]. In form-finding, genetic algorithms is generally used to simulate natural dynamic processes for inspiration in form-finding. Some swarm intelligence techniques are also based on the usage of genetic algorithms for form-finding in this context [7].

Genetic algorithms can only be successful under the laws of probability theory through purpose functions when faced with problem types of which solution space is broad, impermanent and complex. In this way, they can find the best solution in minimal time. In the rehabilitation of existing design, architects need just changing chosen parametric value; however, in designs based on genetic algorithms, genetic algorithms can change every part of the design [8].Genetic Algorithms is used in various areas of architectural design. In this paper, we will examine some architectural examples designed through genetic algorithms. The well-known examples are Praxis of Flow (designed by Arthur Azoulai and Melody Rees), Times Eureka Pavilion (designed by NEX Architecture in collaboration with landscape designer Marcus Barnett), Performing Arts Centre for Abu Dhabi (designed by Zaha Hadid), Research Institute (designed by Joseph A. Sarafian), Bionic Tower (designed by LAVA), Shanghai Terrace Installation (designed by Synthesis Design and USC AAC Students in Shanghai), Bloomberg Pavillion (designed by Akihisa Hirata).

Praxis of Flow by Arthur Azoulai and Melody Rees

In the conceptual framework, Arthur Azulai and Melody Rees investigated the potentials of the vast field of movement and circulating forces creating the building with specific topologies along the surface. They studied the morphological structure of San Juan in Puerto Rico and the circulation flow of the area. The free-from project was based on the simulation of self-organising biological systems in which selective decision making is used to form spatial relationships and proper attributions. The curvilinearity of the shell was produced through genetic algorithms based on evaluation data such as the study of the movement and circulating forces. As well as circulation, one of the other key terms in its conceptual phase was continuity of the overall form as a topological surface letting to create the roadways, interstitial interior space, and landscape [9].

Times Eureka Pavilion by NEX Architecture + Marcus Barnett

The conceptual background of the project designed by NEX Architecture and landscape designer Marcus Barnett was based on emphasising the symbiotic relationship between humanities and natural ecosystems through offering an intimate space for visitors. Pavilion was designed for temporary exhibitions. In plan designing, designers benefitted from genetic algorithms based on inspiration by capillary branching and subsequent cellular division of leaves and design of the structure of pavilion inspired by the growth patterns of leaves to form a modular structural grid. The conceptual framework of Pavilion was based on illustrating patterns of biological structures letting visitors experience a meaningful connection to their natural surroundings[10].

Performing Arts Centre for Abu Dhabi by Zaha Hadid Architects

Zaha Hadid Architects benefitted from mathematics, branching and genetic algorithms and natural patterns surrounding the building site to design Performing Arts Centre. In the conceptual phase of design, Zaha Hadid and his collaborator Patrik Schumacher focussed on issues related to evolutionary biology for the emergence and the evolution of the building within its environment. The firm benefitted from algorithms not only for form-finding but also for energy efficiency. The design team also benefitted from different data sets during the design process, such as site analysis, movements in the urban fabric, and diffusion of natural light and ventilation within the building [11].

Research Institute by Joseph A. Sarafian

Joseph A. Sarafian focused on the role of genetic algorithms on the human future and imagined that billions of genetic algorithms act as the mediator between man and reality and shape his existence through their very interactions. For him, the function of genetic algorithms is the carrying out of human desires and the prediction of human behaviours. Starting from these ideas, he designed Bach Multidisciplinary Research Institute inspired by the composition techniques of Johann Sebastian Bach based on weaving voices together in his fugues. In the design of the Research Institute, he benefitted from the idea that synthesising various flows of information creates aspects more extensive than the sum of its parts. To fulfil this aim, he benefitted from genetic algorithms. He tried to design a building acting as an organism and interacting with its environmentand controlling its porosity through algorithms. Here, it is also benefitted from algorithms for optimising lighting, the acoustics of building and institute designed to engage various fields of study, from music and the visual arts to biology and mathematics. The building's form and structure are designed by an agent-based flocking algorithm where agents from various locations on the site create paths following structural burdens, detecting the position of primary and secondary structural elements [12].

Bionic Tower by LAVA

The design team of Bionic Tower focussed on creating an intelligent facade interacting with its surrounding environment for energy efficiency and user comfort through genetic algorithms. The tower was designed to regenerate and re-organise itself benefitting from the laws of regeneration of nature organically. The structural organisation was composed to benefit from embodying efficiencies found within natural structures and architectures. The design team benefitted from computational technologies to generate intelligent agents as the minor units to create more intelligent environments. The team also focused on building's ability of adaptability, responsiveness, environmental awareness, and strength. The building skin is designed to control and respond to external influences like air pressure, temperature, humidity, air pollution and solar radiation. These are performed as an ecosystem within the organic tissue of the city [13].

III. ARTIFICIAL LIFE STRATEGIES IN ARCHITECTURAL DESIGN

Artificial life can be described as the research field examining systems associated with natural life, processes, and evolution by using robotics, biochemistry, and software simulations. Artificial life generally focuses on regenerating aspects of life as biological phenomena artificially [14]. There are three types of artificial life. Software-based artificial life deal with simulating life through computer programs. Hardware-based artificial life deal with applying artificially produced life to robots. Wetware deals with biochemistry to generate artificial biological units such as cells, tissues or organs [15]. The term 'Artificial Life' was coined by Christopher Langton, an American computer scientist, in 1986 [16].

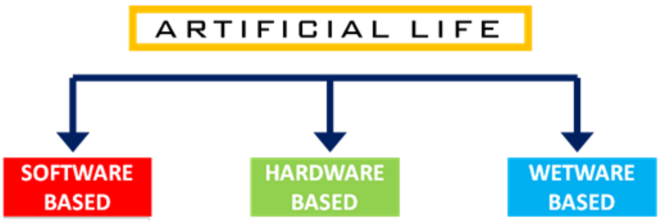

Figure 2 The illustrating graphic shows the types of Artificial Life (AL) (soft AL, hard AL and wet AL) designed by the Authors. The ideas of [17] adopted here.

Although the naming of the area was three decades before, the intellectual background of artificial life can be dated back to John von Neumann and Norbert Wiener. Von Neumann created the first sample of software-based artificial life models called cellular automata to figure out the fundamental attributions of living organisms as a system, particularly self-reproduction and the evolution of complicated structures. Cellular automata are typical artificial life samples abstract and material independent based on information theory [18]. Wiener, the founder of cybernetics, applied information theory and homeostasis to organic systems [19]. As well as software techniques, information theory, and cybernetics and biology, various domains significantly contributed to artificial life studies. Some contributor areas are physics, mathematics, dynamic system theory, statistical mechanics and complex systems theory.

Artificial Life systems are generally classified as complex systems due to including many elements simultaneously interacting with each other. Furthermore, artificial life studies generally focus on types of complex systems, including adaptation and learning abilities. The artificial life field also some similarities and overlapping issues with artificial intelligence, such as examining natural phenomena by simulating and synthesising them [20]. Also, there is a remarkable difference between symbolic AI and artificial life, especially in the process structure. Symbolic AI studies are generally based on specified top-down systems where the role of the controller is essential. However, artificial life systems generally include vice versa techniques and based on the interaction of low-level system units more autonomously. Aspects of artificial life, especially decentralisation of controller, shares essential similarities with some newer trends in AI, including connectionism, multi-agent AI and evolutionary computation [21].

Among types of artificial life, the most contributor area to the realm of architecture is software-based A-Life, and one of the most common examples of soft A-Life is cellular automata. Cellular automata can be described as a discrete, discontinuous model including grids and cells containing different states based on the neighbourhood and growth by describing a complex system by simple individuals following simple rules. The concept was coined in the 1940s by Stanislaw Ulam and John von Neumann [22]. In the 1970s, thanks to Conway's Game of Life, a two-dimensional cellular automaton created by mathematician John Horton Conway became interested in academic cycles [23]. In the 1980s, Stephen Wolfram studied creating ways of one-dimensional cellular automaton and generated rules. Cellular Automata can simulate various systems such as biological and chemical systems in the real world. The space for cellular automata has evolved over several dimensions, from one dimensional to three dimensional. 3D cellular automata are one of the most contributor areas to the realm of architecture [24].

Cellular Automata is generally used for form generation in the realm of architecture. Also, the interpretation of cellular automata architecturally can re/de-construct architectural elements and concepts such as boundary, ground, gravity, and spatial connections, including horizontal and vertical connections in various spatial modules [25]. Cellular automata can balance chaos and order in architecture and can be used in various areas in architecture, from material design to surface creation. The most commonly used cellular automata type in architectural design is the three-dimensional interpretation of Conway's Life Game [26]. Generally, in architectural design processes, emerging information during the design process interpreted in the light of laws of chosen cellular automata type and applied to it from conceptual phase to detail phase of the design process.

Habitat 67 by Moshe Safdie and Nagakin Capsule Tower by Kisho Kurokawa

Habitat 67 was designed by Moshe Safdie as a housing complex in 1967. Its conceptual roots were dated back to his master thesis[27].Nagakin Capsule Tower designed by Kisho Kurokawa in 1972 as a mixed-use complex. It became one of the symbol buildings of Metabolism. Its conceptual background was based on a mentality creating an organic structure formed by humans, machines, and space.The building complex offers an organic way to live and sustain within a changeable nature of the human population and timelimitation. All capsules in this project could regenerate in the face of changing conditions [28].The cellular automata have been not used in the project directly.The design team used some design strategies in the project,which are different from traditionally structuredcellular automata.The project hassignificant similarities to cellular automata-based projects in terms of form structure and function; its cell structured design reflects the modular cellular system.

Experimental Study on Cellular Automata-based Architectural Design by Paul Coates and his Team

In the experimental study of Paul Coates and his team in 1996, they aimed to develop a cellular automata tool as a new modelling device capable of generating forms through extensive state variables in the media of computer-aided design. To achieve this aim, they suggested a three-step studio experiment. In the first step, they focused on the types of relationships between the resultant behaviour of the system and the genetic structure of cellular automata and the application of cellular automata rules to the general system. In the second phase, they focussed on the behaviour settings of cellular automata in an architectural scenario, including operational environmental conditions such as sunlight, direction and cells of cellular automata express states of space such as closed, semi-closed and open space in this step. The final step was associated with the realisation of emerged information in previous steps through materials. They also focussed on the tissue formation capability of cells and applying this dynamism to architecture [29].

Vertical Village by Christiane M. Herr

Christiane M. Herr claimed cellular automata could be an alternative solution against monotonous techniques in architecture. She benefitted from cellular automata to deal with high-density population and their housing demands and the problem of the distorted settlements in Hong Kong and other metropolises in Hong Kong and generated the term 'vertical village' inspired by Metabolism movement in 2003. In her vertical village model, she suggested flexible inner spaces, re-established infrastructures, changeable floors and walls, and extensible units that provide diversification. This structure assessed as a society living like peasants instead of being perceived as overlapping stacks of flats. Her project included local network systems enhancing communications between users and integrated bottom-top design strategy enhanced by this network system with traditional top-bottom strategies. Furthermore, she dealt with monotony in three dimensions through structure containing inner flexibility and outer additions based on cellular automata [30].

Cellular Automata in Architecture Workshop in Architectural Association School of Architecture

In 2014, AA School of Architecture held a workshop investigating the application self-organising and self-assembly systems such as cellular automata, the game of life, and architectural design. They have done this to go deeply into cellular automata theory and practice and define the strategies of control the self-organising system and find the directions of usage in architectural design. The algorithm for space tessellated into truncated octahedrons instead of usual cubic voxels contributed to cellular automata research. The study aimed to develop an algorithm that analyses the system and cellular automata based on the statistical data decides how to change the input parameters – rules of growth or initial generation and modifies the geometric structure of the system given the strategies that are necessary for the achievement of design [31].

Architectural Design using Cellular Automata Workshops by Mirjana Devetakovic and the Team

Mirjana Devetakovic and her team organised workshops dealing with examples based on applying cellular automata to architectural design by benefitting from Conway's two-dimensional Game of Life. In software, cellular automata included some parameters such as basic fictionalisation, computational theory definition, numbers of layers, position and rotation of the system, the ratio of cells, colour series of layers of cells, transparency, distances between cells, lighting and shadow. The cellular automata software has had some attributions such as processability, interpretability, diversification. The team examined the potentials of creating spatial form through software in a studio work called 'Exploration through Designing' in 2009, including three steps: primary production, composition, and conceptualisation. The essential production step focussed on production ways through examining relationships between folded-derivation of cellular automata and spatial form derivation. The composition phase dealt with spatial organisations based on the integration of different version cellular automata. The conceptualisation phase handled with supporting implementations through contextual references to gain more profound meaning in the application. The team organised another workshop based on the same idea in the same year, but they benefited from Bernard Tschumi's follies differently from the previous one. They divided the team into three groups. The first group dealt with differentiation of proportions, patterns, holistic geometry of initial cell and the second group handled with additional concepts such as transformation, fragmentation, composition, multiplication and fractal modification of initial cell. The third group cope with the derivation of complicated surfaces through cellular automata [32].

Voxel-Based Geometries by Michael Hansmeyer

Michael Hansmeyer benefitted from the volumetric cell as voxel-based geometries to generate new form-finding strategies. In his approach, voxels contain data that can interact with data of proximate voxels according to pre-established sets of rules. By iteratively conducting these interactions, data can be propagated through the voxel space. Eventually, this data can be visualised, either as individual elements or as a hull surrounding elements with specific values. Two broad algorithms to control the voxel interaction are explored: cellular automata similar to the Game of Life, and reaction-diffusion processes. In the former process, cells usually have only one of two states (on/off), the choice of which depends on the combination of the states of surrounding voxels. The latter process, reaction-diffusion, simulates chemical interactions between substances contained in the voxels. This process is associated with pattern formation on several organisms and in the fields of geology and ecology [33].

The examples which we mentioned above show us that artificial intelligence-based principles can be considered a subfield of design computing, emphasising computational creativity and knowledge engineering. The main objectives of the field arethe development of algorithms to simplify or automate architectural design partially. Definition of computable models of architectural knowledge needs to be general and flexible as much as possible. Automatic generation of variations on architectural features, structures and object would be enriched the design capacity.

Figure 3 Some essential points of artificial life-based strategies in architectural design, the graphic designed by the Authors.

IV. CONCLUSION

Soft computing strategies also influenced by dynamic system theory and its particular branch of chaos theory dealing with explaining dynamic reality in physics holistically. Soft computing techniques pioneered new developments, especially in computer-aided design and implementation of artificial intelligence in architectural design. Fuzzy logic and evolutionary computing techniques are widely preferred by architectural designers because they emphasise the unsolid problem-solvingtruths like a human brain.

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