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Review

SWARM INTELLIGENCE IN ARCHITECTURAL DESIGN AS A TECHNIQUE OF AI

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Abstract

The article mainly focusses on a discussion about the recent development of AI techniques in the field of architectural design. The motivation point of the study is based on the latest changes in Soft Computing Techniques to deal with the design matter. This article basically aims to discuss how artificial intelligence ideas evolved by the help of the analytical and mathematical philosophies, and it asks how swarm intelligence is applied in the field of architectural design. As the methodological way, the article uses a theoretical approach to reveal the background of the article intelligence's idea. Therefore, it focuses on some architectural examples -created through swarm intelligence strategies- that are named as 'Seroussi Pavillion' designed by Alisa Andrasek, 'Structurally intelligent swarms' designed by Joshua M. Taron, 'Swarm Chandelier' designed by Zaha Hadid, and 'The Sequence' designed by Arne Quinze, lastly Tyler Julian Johnson's Swarm-Based Project. The limited number of studies and sources in the area created the main restriction of this article. As the contribution to the body of literature, this article shows that the swarm algorithm in architectural design provides new ideas for the architects and artists, and it is a highly potential approach to support the design process.

Keywords: Architectural Design; Soft Computing; Swarm Intelligence

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Derleme

BİR YAPAY ZEKÂ TEKNİĞİ OLARAK MİMARİ TASARIMDAKİ SÜRÜ ZEKÂSI

Özet

Makale, temel olarak mimari tasarımda Yapay Zekâ temelli tekniklerin gelişimi üzerine bir tartışmaya odaklanır. Tasarım problemlerinin üstesinden gelmek amacıyla esnek zekâ tekniklerinde meydana gelen güncel değişimler, çalışmanın motivasyon noktasını oluşturmaktadır. Makale, temelde yapa zekâ kavramının analitik ve matematik felsefesi yardımıyla nasıl geliştiğini tartışmayı amaçlar ve sürü zekasının mimari tasarım alanında nasıl uygulandığını araştırır. Yöntem olarak, yapay zekâ arka fikrinin arka planını göstermek için teorik bir yaklaşım kullanır. Bu sebeple, makale sürü zekâsı stratejisiyle yaratılan; Alisa Andrasek tarafından tasarlanan 'Seroussi Pavillion', Joshua M. Taron tarafından tasarlanan 'Yapısal olarak akıllı sürüler', Zaha Hadid tarafından tasarlanan 'Swarm Chandelier', Arne Quinze tarafından tasarlanan 'The Sequence', ve son olarak Tyler Julian Johnson'ın 'Sürü Temelli Projesi' gibi bazı mimari örneklere odaklanır. Alandaki kaynak ve çalışma azlığı bu makalenin temel kısıtlamasını yaratmıştır. Çalışma literatüre katkı olarak, mimari tasarımdaki sürü algoritmasının, mimarlar ve sanatçılar için yeni fikirler sağladığını ve tasarım sürecini destekleyerek yüksek potansiyelli bir yaklaşım olduğu göstermektedir.

Anahtar Kelimeler: Mimari Tasarım, Esnek hesaplama, Sürü Zekâsı

1. INTRODUCTION

Since the beginning of artificial intelligence studies, one of the main problems has been to understand the mechanisms of design thinking as a problem-solving activity and modelling it through computer simulations as it is known that design activity is one of the more complicated activities of human cognition. It is also too hard to apply to artificial intelligence owing to its ill-defined structure. The design process is open more chaotic situations, randomness and probabilities, polyvalent and multivariate activity when compared with other human activities. Because of these attributions of design activity, design cognition dealing with cognitive aspects of design process emerged as a new field after the 1970s. Design cognition generally deals with issues such as the manifestation of design thinking through representation tools, spatial configuration and conceptualization (especially in architectural design), design patterns and conceptual design, design rationale and role of agents in design, visualisation and perception in design, knowledge-based design and design learning, nature of design methodologies and design thinking, decision making and creativity in design. Thanks to advances in soft computing techniques used Artificial Intelligence studies after the 1990s, knowledge in design cognition studies can be modelled and analysed through computers. Soft computing techniques are very suitable for research because they are based on imitating human thinking style (Hight, 2006). In this context, this article intends to reveal the contribution of how soft computing techniques to computational architectural design. Then it discusses how bio-inspired computing in architectural design evolved, and then it focusses the swarm intelligence strategies on the field of architectural design.

2. THE THEORETICAL BACKGROUND

The theoretical background of artificial intelligence strategies can be based on the roots of the mathematical and analytical ideas, philosophy of mind, and soft computing shifts.

2.1. The Mathematical & Analytical Roots of AI

Although ideas on creating intelligent machines can be dated back to the beginning of the intellectual history of humankind, one of the main essential steps for building smart devices appeared as the foundation of computer science in the 1930s. Computer science emerged thanks to the contributions of some ideas in Philosophy of Mathematics based on combining mathematics with logic and creating systems modelling reality in a formal system. One of the most significant contributions were made by Logicism dealing with reducing mathematics to logic and Formalism assessing mathematics as speculation of symbols under the laws of formal logic. This formalist beginning of computer science shifted due to the demands of users and experts. Experts generated new techniques based on different philosophies, mentalities, perspectives for dealing with more complicated issues (Müller, 2018; Dietterich & Ullman, 1986).

2.2. Philosophy of Mind & AI

In 1950s Alan Turing, founder of computer science, brought forward an idea that computers can imitate human intelligence and tried to support his opinions with some proofs in his famous essay 'Computing Machinery and Intelligence.' About four centuries before Turing, French Philosopher Rene Descartes claimed mind and body could not be reduced to each other because they are two discrete substances in themselves and claimed the impossibility of creating thinking machines. Cartesian Ideas focusing on the content of mind and relationship between mind and body was very influential during one and a half-century after him. However, Immanuel Kant concentrated gaining knowledge process as a function of the mind to find the limit of human knowledge instead of metaphysical aspects of mind. He paved the way of philosophies dealing with investigating the role of the mind. After a century, Charles Darwin examined the functions of mind in terms of adaptation and evolution. Functionalism reduced mind to its operations and focused on dealing with the mind as the collection of functions. Benefitting from these ideas Alan Turing founder of computer science and AI studies, went further and concentrated on the critical word 'imitation'. For him, if imitating of functions of mind can be achieved by a machine, people will be able to call them intelligent machines (Wells, 2006; Leach & Yuan, 2019).

2.3. Soft Computing & AI

The shifts paved the way of artificial intelligence studies. Briefly, at the beginning of artificial intelligence studies, experts benefitted from formal and syntactical strategies in the philosophy of mathematic and early Analytic Philosophy and ideas in steams of the philosophy of mind reducing mind to its functions. From the 1950s to 1990s, these techniques were called hard computing techniques. However, there was a significant problem in these studies when faced with hard-formalised areas such as architectural design. As known, the nature of architectural design as one of the creative activities of humankind is existential and unique and open to probabilities and vicissitudes and needs thinking many variables at the same time. Due to these difficulties, AI experts tried to find new techniques imitating human thinking style, and these techniques have been called soft computing techniques. In today, application of fully developed

AI to architectural design is in the hypothetical phase, but some of the soft computing techniques used in AI studies are also being used in computer-aided design (Casey, 2016).

3. APPLICATION OF SOFT COMPUTING TECHNIQUES TO COMPUTATIONAL ARCHITECTURAL DESIGN

Benefitting from computers in architectural design can be dated back to 1960s, two decades later than the invention of digital computers. At the beginning of 1970s, the computer-aided architectural design emerged as a new research field in academic circles, and the middle of 1980s, programs designed in this domain began to be used by companies to generate 2D drawings and 3D models through the computer (Lin, 2007). Since then, computers have been used for different purposes in the realm of architecture such as 3D modelling, animations, creating simulations related with the functional quality of space (ventilation, heating, structural durability), cost, time and labour management of building site, communication during design and construction process, controlling material quality and stock status, cost estimation, form generation. Subsequent developments in AI after the 1990s paved the ways of ideas based on the application of AI to different domains such as architectural design. These ideas emerged in the realm of architecture as creating more intelligent and interactive environments, programmable, autonomous, and informative spaces, supporting architects in such areas as decision making and optimisation. In this context, in the realm of architecture, most contributor branches of soft computing in AI are Evolutionary and Fuzzy Systems (Lee, 2019).

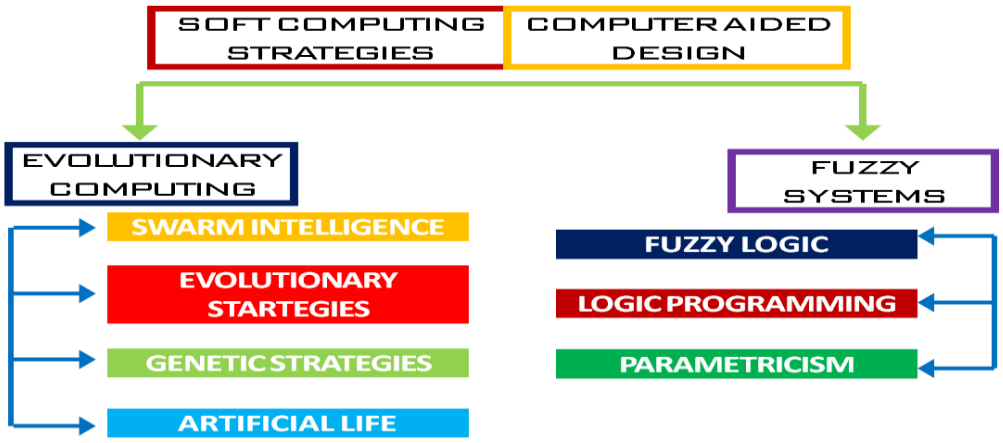

Figure 1. Branches of Soft-Computing also used in Computer-Aided Architectural Design (Source: Authors, adopted by Chiu, 2011).

4. EVOLUTIONARY & BIO-INSPIRED COMPUTING IN ARCHITECTURAL DESIGN

The emergence of Evolutionary Computing techniques based on benefitting from laws of evolution and genetics can be dated back to 1960s (Aryanpour, 2012). In 1960, Lawrence Jerome Fogel devised evolutionary programming to benefit from simulated evolution to enhance learning abilities of artificial intelligence. In the same year, Ingo Rechenberg launched a new term as Evolutionary Strategies based on benefitting from adaptation and evolution strategies artificially for optimisation. In 1975, one of the revolutions emerged in this area thanks to the invention of Genetic Algorithms by John Holland. Genetic algorithms can be defined as the step-by-step processing set of operations benefitting from evolution strategies

for problem-solving and optimisation. The invention of genetic algorithms paved the way of the invention of genetic programming encoded as a set of genes evolved by genetic algorithms. In 1992, John R. Koza invented genetic programming. About the beginning of 1990s, swarm intelligence as one of the other branches of evolutionary computing emerged. Swarm Intelligence studies inspired by software-based artificial life studies and one of the first interference was made by Craig Reynolds. Craig Reynolds designed a program modelling flocking behaviours of birds called Boids. In 1992, Marco Dorigo invented ant colony optimisation algorithms benefitting from an artificial simulation of colony behaviours of an ant for optimisation. Since the mid-1990s, evolutionary computing techniques have begun to be used by architects. One of the first attempts was made by John H. Frazer, founder of evolutionary architecture, with his book 'An Evolutionary Architecture' in 1995. In his book, Frazer searched the ways of form and structure generation by benefitting from the laws of evolution and adaptation. In the same year, James Kennedy and Russell Eberhart formed particle swarm optimisation algorithm based on swarming theory and software-based artificial life principles. In the same year, Rainer Storn and Kenneth Price launched the term differential evolution based on optimisation of a candidate solution following given quality by trying to improve repeatedly like development. In 2001, Zong Woo Geem introduced harmony search algorithm influenced by the improvisation of musicians based on trying possible musical notes as candidate solutions for best harmony. In 2005, Dervis Karaboga invented artificial bee colony algorithms benefitting from colonial behaviours of bees and in 2008, Xin She Yang developed firefly algorithms influenced by the flashing behaviour of fireflies (Baydogan, 2013, p. 71-2; Chella, 2013).

4.1. Swarm Intelligence in Architectural Design

Swarm intelligence can be described as the collective behaviours of artificial or natural self-organised and decentralised systems (Aryanpour, 2012). Swarm behaviours of animals inspire swarm intelligence strategies in computer media. Swarm behaviours in nature emerge to enhance food-finding, protection mating and sufficient energy using abilities of limited-skilled animals when they are individual. There are different words used to express the swarm behaviour of other animals. For instance, for insects, the term 'swarm' is used. For birds 'flocking', for quadrupeds 'herding' and fish 'shoaling' or 'schooling' is preferred. To simulate this behaviour mathematically to implement them to computer media, experts have tried to represent three rules emerging in swarm behaviours. These are separation as moving in the same direction with neighbours, alignment as remaining close to neighbours and cohesion as avoiding collisions with neighbours (Chen, 2015, p. 3-9).

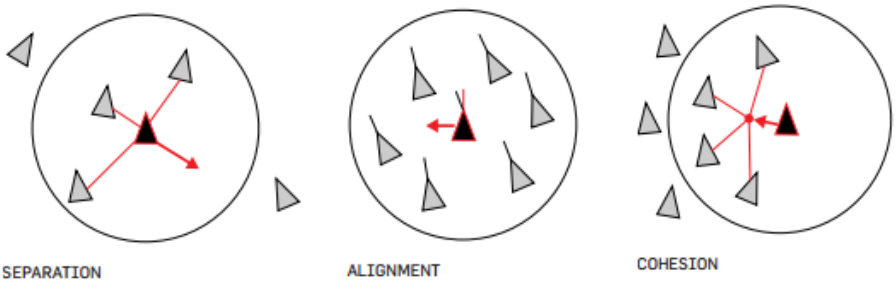

Figure 2. From left to right, three rules emerging in swarm behaviours (Chen, 2015, p. 6).

The term swarm intelligence first introduced in 1989 in robotics by Gerardo Beni and Jing Wang to express emergent collective behaviour in the context of cellular robotic systems. Steven Johnson has searched one of the early hypothetical application potentials to the realm

of architecture in his book 'Emergence: The Connected Lives of Ants, Brains, Cities and Software', published in 2001. In his novel, he dealt with the idea based on creating a form of living especially for humans benefitting from the emergence logic of swarm behaviour of animals and examined the similarities between the smallest scale ants to the larger-scale cities. In architecture, swarm intelligence investigates the role of agency within the generative design process, and architects can benefit from swarm intelligence for deconstructing modernist tectonic hierarchies. Swarm intelligence is used in architecture in such areas; visualisation, self-organisation of multi-agent system, architecture form design, urbanism. Today some architectural firms and star architects are benefitting from swarm intelligence for form generation, structure finding and enhancing space quality by translating mathematically modelled animal particle system to architectural tectonics (Chen, 2015, p. 2-7). Today, swarm intelligence is used in architecture by these firms and architectural schools for architectural design; Zaha Hadid Architects, London; Kokkugia, New York and London; Biothing, London; R&Sie(n), Paris; Cecil Balmond, London; Casey Reas, Los Angeles; London and Foster + Partners, London; and schools: Architectural Association; UPenn; Columbia GSAPP; TU Delft; CITA and USC (Hight, 2006; Wiesenhuetter et al., 2016)

Figure 3. Illustrations depicting swarm behaviours (Chen, 2015, p. 3-5).

4.1.1. Some examples created through swarm intelligence strategy

Seroussi Pavillion Project is created in 2007 by Alisa Andrasek and her team benefitted from self-modifying patterns of vectors, based on electromagnetic fields. In designing a planning process, team inspired by the logic of attraction/repulsion trajectories and lifted designed plan via a series of structural micro-arching sections through different frequencies of a sine function. Its section intended to allow the adaptation of building to the environmental conditions and built area as a steep hill. Six different geometrical systems were used for design and are all steaming out of primary trajectories (Seroussi and Guenoun, 2007). The second example named as 'structurally Intelligent Swarms Project' of Joshua M. Taron. It is designed structurally intelligent swarms to search the relationships between dynamic swarm information and static instance buildings designed through swarm intelligence and contributions of swarm intelligence to the development of any given project. His research accesses and makes use of the incredible amount of latent information within frozen instances of a swarm to discover new structurally informed morphologies and suggests a set of solutions instead of only one strict solution. He problematised the creation of functional agent-based spaces and their relations with analytical software based on feedback loops and efficiency of application of swarm intelligence to architectural design (Taron, 2009; Taron, 2012). The third project of Arne Quinze as 'The Sequence' generated an installation in 2008. This focussed on interactions of citizens to bridge the communication gap between people by developing movements in the city by deconstructing people's familiar perceptions, acceptances, expectations from statues and

gives people a moment to reset their minds and think about what's going on in Flemish Parliament and the House of Flemish Representatives. He used curves, lines, colours and movement in his pieces for providing a feeling of movement and fluidity that combine to create a large frame structure. He witnessed his installations became as places where people meet each other again and start conversations (Lacoere and Quinze, 2009). Then, we need to mention the 'Swarm Chandelier' designed by Zaha Hadid benefitted from swarm behaviour for abstracted organic form generation in her design 'The Swarm Chandelier' in 2006. Her design has no internal light source and calling her design as a chandelier is formidable. However, it is an example of a recent phenomenon whereby leading designers and architects produce objects that are less about their functionality than they are expressions of their conceptual or theoretical exploration. It was manufactured by British Furniture Company Established & Sons and including 16,000 suspended black crystals, each painstakingly suspended by hand on individual wires. In the conceptual level, the black crystals are like a swarm of many birds or insects that behave as a united entity, moving together as a single kaleidoscopic organic form (Abdullah, 2013). The last example is based on Tyler Julian Johnson's swarm-based project. In the context of the project, Johnson focused the role of agency in swarm intelligence based computational architectural design and casting a simple decision-making ability into agents capable of self-organising into an emergent intelligence. He dealt with combining swarm intelligence and architectural theory through technical codes. In his project, he generated new simulations of vector-based swarm systems and benefitted from these systems for developing an architectural design methodology operating within a topological substrate. Simulation in his project was written in Processing, subdivided with a Rhinoscript, iso-surfaced with Processing, and rendered with V-Ray for Rhino (Johnson, 2010).

5. CONCLUSION

Since the beginning of ideas in human history, one of the main breath-taking questions of mankind was about creating thinking machines. Thanks to the contributions of Analytic Philosophy and Philosophy of Mathematics in the late 19th Century and 20th Century, computer science emerged as a significant development in terms of creating intelligent machines and experienced developments in computer science in the last fifty years encouraged AI experts more and more for building intelligent machines as intelligent as humans. Initially, AI studies were based on formal techniques focusing on accurate solutions. However, formal techniques in AI called hard computing were insufficient to deal with probabilities, chaotic manners, and ill-defined structures such as architectural design. After the 1990s, AI research generate new techniques called soft computing trying to imitate human thinking style to deal with probabilities, multivariable issues, ill-defined areas, and vicissitudes. Today, some of the soft computing strategies used in the development studies of AI has also being used by architects for architectural design, spatial analysis, form generation, design cognition. Soft computing techniques, such as swarm architectural design approaches commonly used in the realm of architectural design now. In architectural designing, swarm intelligence offers a high potential of solutions that are fit to the design criteria.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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