Artificial Intelligence Aided Architectural Design

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Tools and methods used by architects always had an impact on the way building were designed. With the change in design methods and new approaches towards creation process, they became more than ever before crucial elements of the creation process. The automation of architects work has started with computational functions that were introduced to traditional computer-aided design tools. Nowadays architects tend to use specified tools that suit their specific needs. In some cases, they use artificial intelligence. Despite many similarities, they have different advantages and disadvantages. Therefore the change in the design process is more visible and unseen before solution are brought in the discipline. The article presents methods of applying the selected artificial intelligence algorithms: swarm intelligence, neural networks and evolutionary algorithms in the architectural practice by authors. Additionally research shows the methods of analogue data input and output approaches, based on vision and robotics, which in future combined with intelligence based algorithms, might simplify architects everyday practice. Presented techniques allow new spatial solutions to emerge with relatively simple intelligent based algorithms, from which many could be only accomplished with dedicated software. Popularization of the following methods among architects, will result in more intuitive, general use design tools.

Keywords: *computer aideed design, artificial intelligence,, evolutionary algorithms, swarm behaviour, optimization, parametric design*

INTRODUCTION

Tools used by architects are constantly evolving. From sketches, two-dimensional drawing and physical model to creating advanced design tools dedicated to particular solutions. Contemporary architects often use an advanced computational system to create complex forms and gain means to control and change it freely. However, most of the currently available designer's digital tools are limited to the predefined commands. The narrow scope of tools, put against the complex architectural vision, encourages the designers to create their own algorithms, based on previously dedicated to different scientific fields. Most of them are based on hierarchical and almost linear approach towards creation process.

Nevertheless more and more attention is brought towards newer design techniques based on heuristic approach. Due to the shift in the understanding creation process, they allow us to create form and architectural vision in non-hierarchical way with a significantly different approach to problem-solving solutions. Commonly this approach is based on predicted assumptions. However, the form created in a nonhierarchical way can be based on computer learning process, that induces artificial intelligence to the discipline.

The change is visible in contemporary approach towards form creation. Designers create their structure on the provided input data that can be gathered in a traditional non-computational way or using advanced automated computational system, rather than based on their subjective personal artistic vision. Both algorithmic and data based methods led to form creation process that is entirely adaptive at design all stages. It is important to point out that all of the algorithms and methods should be moderated by designer, who is responsible for the actual, full-scale architectural form, and based on their experience and preferences.

The article will discuss contemporary used by the authors design techniques that lead to the usage of automated systems based on the selected forms of artificial intelligence algorithms. Among many definitions of artificial intelligence, depending on the research field being discussed, is commonly described as method of "achieving complex goals in complex environments". (Goertzel,2006) The advantages and disadvantages will be analyzed in the scope of recent discoveries. As results will show investigated methods have a lot in common and may offer valuable tools for designers. The aim of the article is to present currently applied set of algorithms, amplifying architectural design tools set, in the optimization process, behavior-based design and supervised machine learning approach.

ARTIFICIAL INTELLIGENCE ARCHITECTURAL DESIGN

Computing in architectural design is based on calculation and automation. All design software offer various automated tools that support the creative process. In terms of computer automated design the most relevant once, are those that use visual scripting, that allow user to compose own algorithms by common programming language or visual scripting techniques. No other systems give designers such a high level of control and possibilities to create their own design tools, fitted to their needs and habits. The automated design systems are commonly used in contemporary architecture, because of their potential to increase productivity and freedom of modification even in most complex environments by developing custom, topic depended tools.

Throughout the many algorithmic design strategies the set of following brings computational architecture toolset towards artificial intelligence approach:

- Evolutionary algorithms
- Swarm intelligence
- Neural Network

COMPUTATION AIDED DESIGN

We can distinguish many different forms of artificial intelligence approach that are being used in design processes. From automation with a low level of autonomy, to swarm intelligence and neural network that can achieve high levels of autonomy. Nevertheless, they all introduce a new way to create architectural form. That often lead to new spatial effects.

Moreover, there are two main models of artificial intelligence, there are subsymbolic systems and symbolic systems. The symbolic systems are created in the forms of algorithms, where the basic parameters have to be analyzed in a strictly hierarchical way. Therefore they are less autonomous and give their creators higher level of control.

Whereas the symbolic system can be described as autonomous design processes that create a form in a non-hierarchical way, where based on complex dependencies. Where a difference in input parameters can entirely change the way the system works and creates form. However, they can provide a high freedom of choice in many achieved results that can have different levels of computation.

Considering the complexity of the architectural design process and a vast number of documentation to be generated due to construction process specificity, advanced, unified and data- based project management systems should be simultaneously developed. In order to achieve best possible computing results, architectural design should be considered as a data processing. Although the following author's examples are rather conceptual geometries, than architectural forms, it is important to mention that in future, fully user ready A.I. systems should be based on the structuralized data, what in a terms of architecture is provided by Building Information Modelling process.

EVOLUTIONARY ALGORITHMS

Evolutionary Algorithms are a class of algorithms inspired by processes of biological evolution such as reproduction, mutation, recombination and selection. During the consecutive process algorithm's parameters are verified and adjusted. The system of optimization relies on the set of four basic rules: selection of the reproduction best-fit individuals, new individuals breed through mutation process, evaluation of the individuals fitness (Hirst, 1997) and replacement of the least fit individuals. Evolutionary Algorithm computational model enables adjustment of the input parameters, resulting in the optimized configuration in the reference to the set goals.

Introduced by L. J. Fogel in the 1966 Evolutionary Computing (Fogel, Owens and Walsh, 1966) became one of the most common problem- solving method, finding its application in the fields of signal and image processing, computer vision, pattern recognition, industrial control and aerospace engineering (Cagnoni, 2000). In the domain of evolutionary computing, genetic algorithms (Mitchell, 1996) are the most widespread type of the multi-criteria optimization methods. Therefore they are becoming the matter of interest for artists, designers and architects. The scope of possible application of the evolutionary algorithms in the field of architectural design is being explored from the middle of 1990's (Frazer, 1995), as the tool being able to produce solutions to problems which structure could not be clearly understood.

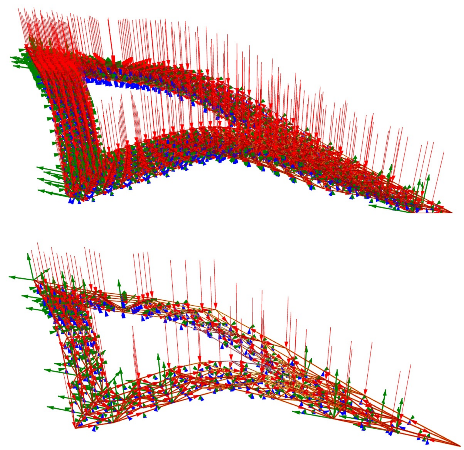


Figure 1
Comparison of the initial and optimized spatial structure.

The potential of genetic algorithms has been used in following research project in order to optimize the objects structural topology, cross-section and materials type selection. The goal of the optimization was to reduce the materials usage, with the possibility of influencing on both, the project expenses and energy demand during the fabrication process. Simultaneously the counter goal was set in order to avoid minimizing the material to a level below maximum possible structural displacement value. The aim of the algorithm was to influence the spatial structure without having the impact on the visual form. That gave the designer a full control over the architectural design and used the algorithm as an advanced problem-solving tool. The spatial optimization process resulted in reducing the maximum structural displacement value by 6% and material usage by 42% from initial form proposed by the designer (Figure 1).

The project transformation in the form of the genetic algorithms is the answer to the question related to the way of inspiration to the nature in architectural design, distinguishing visual nature inspiration from biomimicry (Benyus, 2002). The usage of many of the bio- inspired algorithms in the field of architecture are driven by the trend of the finding free-form design. Within geometrically advanced concepts, the need of the optimization process is hard to deny, considering the advance of the project's complexity and multiplication of the constraints in the various forms of environmental and technical requirements. Regardless of the tools range selection the role of the designer in the process is always crucial, because of the responsibility to balance the importance of various factors in the form creation process.

SWARM INTELLIGENCE

A considerably new direction in creative process has emerged based on a bottom-up approach to both algorithmic design and computer aided fabrication (Augugliaro, Lupashin and Hammer 2014). Behaviour-based solutions do not require a high-level control of the system, avoiding complex multi-parameter form-finding mechanism. Bio-inspired algorithms became a foundation for a non-linear and non-hierarchical approach for solving advanced geometrical issues.

The subject of swarm intelligence application was researched in following experiment based on the bird flocking (Chazeele, 2014) - a collective behavior characteristic to animals of similar breed and physical appearance, aggregated together to act as one bigger, multi-element organism. From a mathematical point of view, it is an emergent behavior arising from a simple set of rules, built by self-propelled entities, that does not require external coordination influence. Virtual control of swarm behavior and its possible application became a substantial topic in contemporary generative design due to accessibility in many design software tools based on boids (Reynolds, 1987) library.

The performed experiment explores the potential of swarm intelligence (Bonabeau, Dorigo and Theraulaz, 1999) during the form finding process. The goal of the algorithm was to generate a spatial structure between two predefined perpendicular areas within a distance of 640cm, at the same time avoiding intersection with a building elements in its pathway and creating a possible to fabricate form based on predefined modules. Each of the individual agents had a set of equal parameters based on three of the Craig Reynold's boids rules: separation, alignment and cohesion. Separation enabled keeping the distance from the surrounding agents in order to avoid their collisions and to preserve the flock size as a whole in order to fabricate the structure. Alignment kept the flock movement in a fluent stream. Cohesion feature was used for two purposes: to create a target for flock movement in the second area and keep the swarm from disjoining into separate groups.

The fabrication phase required in the first step a recorded flock movement data processing. Each of the iteration, resulting in the flock translocation, was recorded creating the points cloud representing the paths of the agents (Figure 2). Generated points cloud was voxelized into the cubes with edge size 100mm or 200mm, approximating the agents recorded coordinates. The generated model has been build with cut polystyrene foam, successfully joining two goal areas, avoiding collisions with a building interior elements- concrete beams, stairs and rails (Figure 3). Collective behavior (Giddings, 1908), based on the swarm intelligence represents macro-scale intelligent system set of simple rules at the local level, which provides designers an efficient and simple tool generating bio-inspired complex results. Swarm Intelligence as a part of larger artificial intelligence system might extend its capabilities that go beyond human control systems.

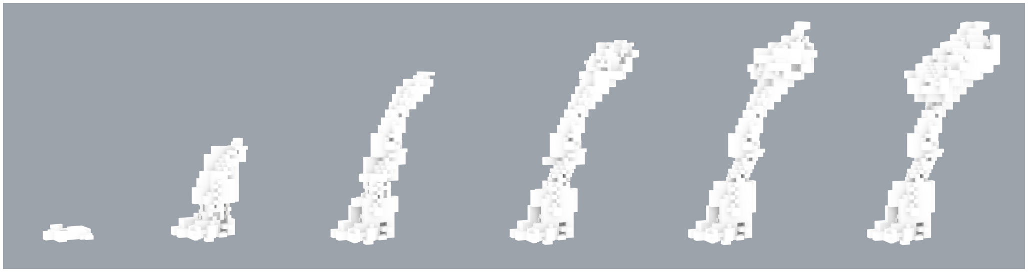


Figure 2
Stages of form creation with swarm intelligence

Figure 3
Spatial installation created with swarm intelligence

NEURAL NETWORK

Machine learning (Samuel, 1959) became one of the most promising computing method (Isaev and Smetannikov, 2016). According to Moore's law, it has accelerated in the recent years by the decrease of the cost per computing operation and anticipated a constant increase in the available computing power (Moore, 1965). Machine learning application can be found on programming on the everyday basis (Jordan and Mitchell, 2015). However, it is still limited in the field of architectural design tools. The most commonly used method- artificial neural networks (Nikola and Kasbov, 1996) are an artificial intelligence approach, originally inspired by biological neural networks (Thomas and McClelland, 2015). The system enables training the artificial neural networks based on the provided examples (training set) in the form of input parameters and corresponding output values, during the supervised learning process (Mohri, Rostamizadeh and Talwalkar, 2012), what can replace complicated algorithms design by learning based on the provided set of the examples.. Despite the growth of machine learning usage, the architectural practice on daily basis still relies on computer-aided drawing and building information modeling. Applicated computational methods in the form of automated drawing board are rarely augmenting the design process.

The conducted research in the field of application of the artificial neural networks, puts the algorithm in the position of the co-designer, being able to generate the possible spatial variations of the examined form, which in the advance can be used as the final solution or inspiration for a further design process. During the experiment, artificial neural networks were trained based on the detailed configuration of the Roman Corinthian order capitals. The network dataset consisted of the samples that enabled analysis of the local deformation. The input data were the sample coordinate values, surface normal vector and volume center plane deviation. The output data consisted of detail displacement values that were calculated from the base surface. During the back-propagation of errors learning procedure (Rymelhar, Hinton and Wiliams, 1986) artificial neural network was provided with 28 900 samples resulting in the Mean Square Error (Lehmann and Casella, 1998) below the value of 0.001. In the result successfully trained artificial neural networks was able to generate 3-dimensional variations of the new capital forms based on the given input parameters, both purposeful and random. The algorithm results,

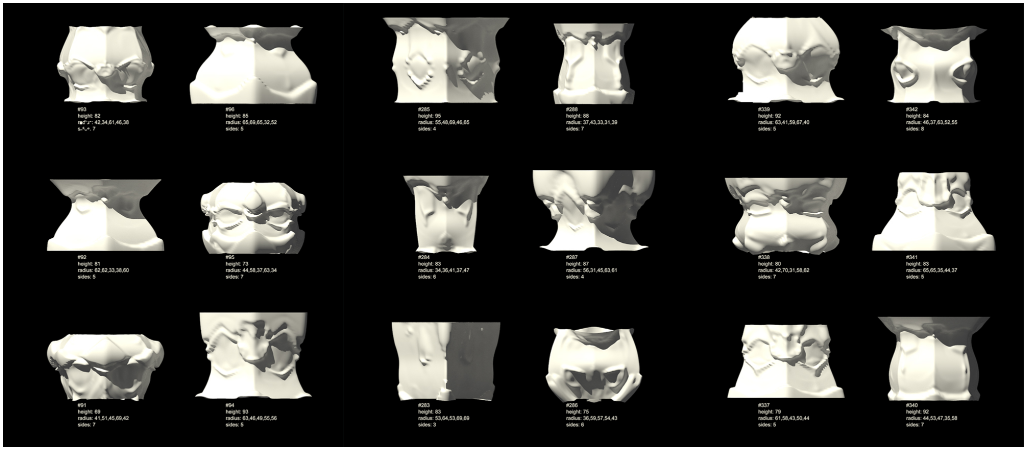


Figure 4
Capitals automatically design with machine learning

stored in the form of the capitals catalog, enables augmenting the design process by computer- generated solutions (Figure 4). Neural networks, that are less predictable, intuitive, resembling human-like decision-making process, became a way of data computing that is able to extend the set of architectural computational design tools.

The possible application of the machine learning in the architectural design process might take place during all of the planning phases. Both repeatable and predictable activities can be easily replaced by machine learning tools in the first place, by teaching the system decision-making based on the work performed by the architects. Introducing the complex machine learning methods approaching the artificial intelligence to the architectural and product design might redefine the value of the algorithmic design from the computational tool, towards becoming the equal collaborator.

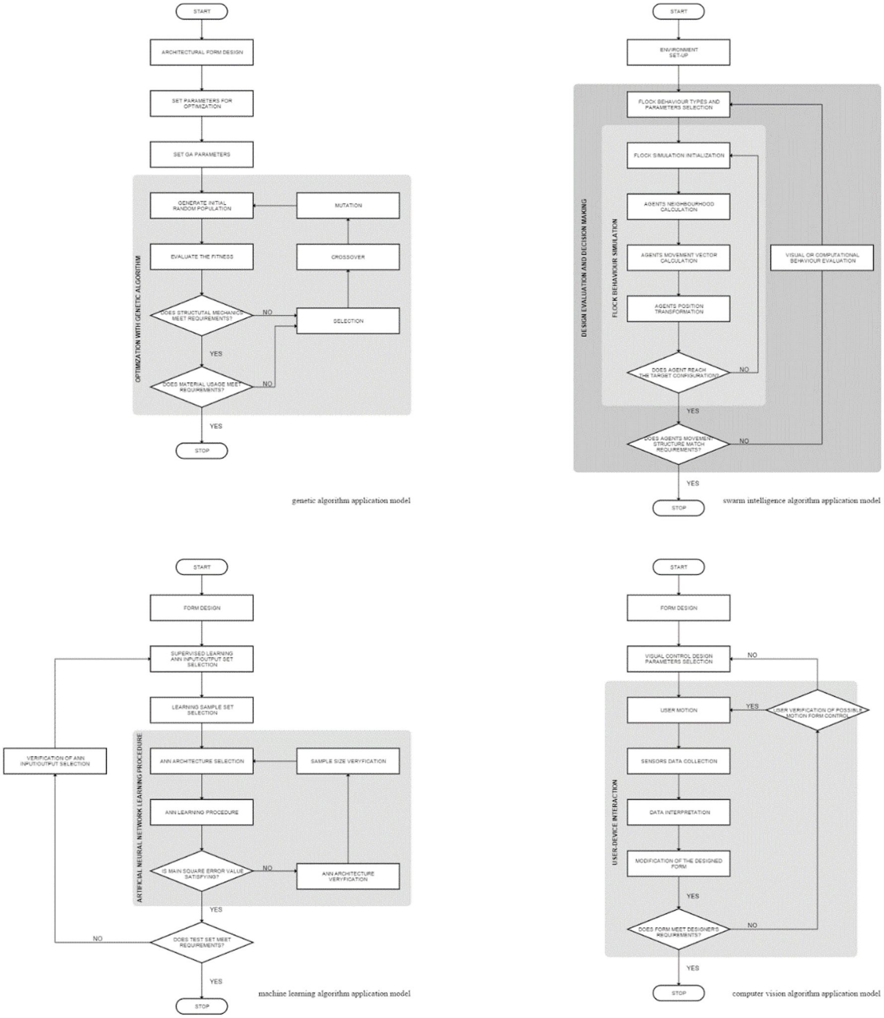
DESIGN PROCESS MODELS

Most of the analyzed design process computational models are based on the same principles- user defined a set of rules (Figure 5). However what is mainly distinguishing them are their relations towards the hierarchy and user decision importance. In a case of basic once like computer vision, all the criteria are predefined and constant. Complex design processes such as neural network gain a freedom to change depending on created environment. Therefore the process constantly changes and the output is often unexpected. Separately analyzed algorithms can be reinforced by their combination, in result creating complex, multi-purpose, general design tool.

RESULTS AND CONCLUSIONS

Contemporary architects in their practice use a variety of different design tools. Their selection is based on the experience, preferences, performance and particular task. From traditional drawing to advanced autonomous systems. The basic digital design tools are a subsidiary of a drawing board. Some of them allow simple forms of automatization, like the array function that is present in most of the contemporary design software. We can definitely point out that in general, according to their purpose, they improve the efficiency of a design process. However, in many cases, the result is opposite, because of the need for the manual designer's evaluation, decision, and control on every level of his project. Therefore many of traditional basic computer-aided design tools used nowadays are not capable of fulfilling the needs of

Figure 5
User defined set of rules in design process



contemporary architectural design practice.

The introduction of emerging complex tools to the discipline enables higher efficiency in a creation of complex forms. Investigated design tools are based on both symbolic and subsymbolic systems. Symbolic systems are being created in forms of hierarchical algorithms, where due to selected parameters forms or relations are being created. While in subsymbolic systems the dependence is more fluid and therefore the solutions are less expected.

As results show artificial intelligence is introduced to the discipline in many different design tools. From basic automation and computer vision to advanced neural network and swarm intelligence. This leads to the creation of new spatial forms, which could not have been created in any other way. Emerging tools give more freedom to designers, who can control even extremely fragmented form with a defined set of rules.

Therefore we can definitely argue that artificial intelligence has a potential to change the whole discipline giving it new possibilities and paths to explore. The breakthrough of artificial intelligence became crucial for the change of the way we think about creating architecture. The introduction of automated design system amplified capabilities and role of conceptual thought in a design process. In the near future one can expect digital artificial intelligence aided designer's assistant, which concept can be based on the existing system, taking a primitive forms nowadays, which learn our behavior and patterns of thinking- recently introduced personal assistants such as Siri or Alex, help us find best possible way to solve our problem or suggest other solutions on their own.

Advanced design system can learn the style and manner based on the particular architect projects. Nevertheless, the role of the architect is still crucial because of his responsibility to choose the most suitable solution from many that are computed. It is not to be expected that in near future system will replace humans as designers. Not only because of their complexity, but also due to ever changing needs and our aspirations to create and control environment.

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