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ARTIFICIAL INTELLIGENCE AND ITS IMPACT ON THE TRANSFORMATION OF DESIGN PRACTICE ON THE EXAMPLE OF PARAMETRIC MODELLED ARCHITECTURE. RESEARCH USING MIDJOURNEY GENERATORS

Artificial intelligence (AI) has fundamentally changed the possibilities for architecture. Parametric design is at the forefront of this unprecedented evolution, which is a graphical description of a design problem, in a network of geometric connections that can be processed in various spatial contexts. More than three decades have passed since the first advanced 3D parametric modeling and BIM programs were added to the interdisciplinary communication interface. During this time, digital modeling replacing the analogue process of searching for form was established in architecture theory with thousands of publications and scientific conferences devoted to CAD/CAM/CAE. Currently, such a historic change in the approach to design can be seen in artificial intelligence, which is a way for architects to quickly generate visually attractive ideas, especially for objects with free-form features.

Keywords: artificial intelligence, machine learning, parametric design, digital design, free form

1. INTRODUCTION

The sudden development of artificial intelligence systems introduced a new paradigm in parametric design, where architects gained powerful tools to search for and model forms of complex geometry in the three-dimensional synthetic space. Generative algorithms, based on the machine learning and neural networks, can discover and explore unknown possible solutions, including combinations of large data sets of design constraints and preferences. This is a way to create and improve the most appropriate architectural solutions in iterative relationships, which can be further developed through a process of transformations and matching. At the moment,

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the schemes of artificial intelligence allow the creation of 2D images inspired by exactly what a given author is doing with modern technology.

This article presents one of the first projects in Poland realized as part of the master's thesis at the Faculty of Architecture, West Pomeranian University of Technology with the use of artificial intelligence tools in the Midjourney generator. The analyzed work entitled *Oceanarium in Szczecin* Jacek Czudak received in 2024 the main prize awarded within the Academic Awards of the President of the City of Szczecin in the category of engineering and technical sciences.

2. THE HISTORY OF ARTIFICIAL INTELLIGENCE DEVELOPMENT

Alan Turing (1912-1954) is considered a pioneer of artificial intelligence, who in 1936 developed the concept of a general-purpose computing device called the Turing machine. This simple model of a logic machine naturally led to the consideration of the ultimate possibilities of what were soon to be called thinking machines. Turing himself contributed to the development of modern mathematics, i.e. to the reinterpretation of the theory of computational complexity as a matter of logic, rather than classical arithmetic. The Turing machine became a crucial formal tool for solving various real-world problems of computer science and the practical implementation of algorithms, i.e. an effective method of calculating values. Computers were not tools in themselves, but could also enable a new way of thinking about acquiring knowledge and doing science. In this context, no less important were the Turing tests of the 1950s illustrating the human interaction with artificial intelligence. At an abstract level, the test suggested that if a human interacts with an artificial machine and identifies it as a human, then that artificial machine is considered sufficiently similar to a human.

These achievements provided a reference point for a new field of academic research, artificial intelligence (AI), a technology that was defined in 1956 at a scientific conference at Dartmouth College. By definition, artificial intelligence is “the branch of computer science that enables computers to simulate aspects of human intelligence such as speech recognition, deduction, inference, creative response, the ability to learn from experience, and the ability to draw conclusions from incomplete information. Two common areas of artificial intelligence research are expert systems and natural language processing” [Blanton, Haynes (ed.) 2002: 35-36]. While artificial intelligence (AI), machine learning (ML), deep learning and neural networks are related technologies, the terms are often used interchangeably.

As in the first era of artificial intelligence in the 1950s and 1960s, the second era in the late 1980s and 1990s was built around new and exciting technologies combined with the promise that computers would soon solve all our problems. In the 1980s and 1990s, numerous basic ideas based on artificial intelligence concepts

proved useful in developing decision-support environments and design processes in its various aspects. This change was further driven by the socio-economic change from Ford's multi-series mass production to a post-fordism, in which it is easy to obtain product differentiation, which found its special place in architecture. The development and achievements in the digitization of design integrated with digital fabrication, caused an epochal paradigm shift. The range of designer competences was expanded to model in virtual spaces with the ability of exploring production technologies and the built environment, which with the increasingly complex form of realized objects, became rich in information. In the realization of the art of construction, graphos, rapidographs, and technical scales gave way to digital records of the physical and functional properties of the construction object.

In the 1980s, after many years of research, expert systems such as DENDRAL for the analysis of chemical organic compounds and XCON for the configuration of DEC's VAX computer systems were developed. These systems achieved commercial success and demonstrated the practical application of AI, achieving performance comparable to or even superior to that of humans. In addition to expert systems, machine learning techniques were introduced in the 1980s, which allowed computers to analyze their own results and improve their performance over time. The development of machine learning laid the foundation for a large number of advances in artificial intelligence and neuroscience that were to follow in the following decades. Scientists such as John Hopfield and David Rumelhart developed neural networks that could recognize patterns and formulate decision-making rules based on training data.

At the turn of the 80s and 90s of the XX for architectural designers, the implementation of text-based programming languages into some CAD software packages was certainly important. It is worth mentioning the introduction of the text-based scripting language AutoLISP to AutoCAD 2.1 in 1986, which was based on the LISP programming language, which was originally intended for use in artificial intelligence applications. The LIPS project was created in 1958 by John McCarthy and was a high-level programming language still in use today. At the time, the view was formed that scripting was a tool by which a designer could more effectively express and explore his creativity [Mcculbough 2006: 12-15].

In the history of the development of artificial intelligence, it is worth noting that the Emergent Design Group (EDG) was founded at MIT in 1997, which included computer scientists and architects. The team explored the potential for synergies between architecture, artificial intelligence, artificial life, engineering and materials science to develop a prototype program that would provide new modeling tools in CAD systems. In 2001, Una-May O'Reilly and Martin Hemberg presented the Genr8 program. This was to prove that the concept of generating surfaces by combining L-Systems and evolutionary algorithms were useful in architecture modeling [Q'Reilly, Hemberg, Menges 2004: 48-53].

In the 1990s, it was realized that the second era of artificial intelligence did not meet the expectations equal to its ambitions, which led to a period of extreme disappointment, often referred to as the “second AI winter”. It is only in the third era of artificial intelligence, in which we live today, that we can say that computer intelligence has approached human-level capabilities and is able to perform or even surpass human tasks. This has implications for numerous aspects of architectural design and digital fabrication processes, primarily in terms of rapidly generating ideas, but also eliminating errors and improving quality. The hard-earned experience of CAD/CAM/CAE designers and developers can now be used to inform design, testing, validation, and AI-related policy as well as regulation.

3. AUTOMATION OF DESIGN PROCESSES AND REINVENTING CREATIVITY FOR PARAMETRICALLY MODELED ARCHITECTURE

The development of generative models such as GAN (Generative Adversarial Networks), VAE (Variational Autoencoders) and Transformers revolutionized artificial intelligence, implying changes in the form of generating realistic images, films and text. These models have applications in a variety of fields, from art and entertainment to scientific research and data analysis. This was particularly noticed by architects known for their predilection for parametric modeling and free forms, which in their studio teams initiated a reorganization of the approach to design tasks.

Parametric design is understood as “a process based on algorithmic thinking that enables the expression of parameters and principles by which the relationships between intention and design response are defined, coded and explained” [Woodbury 2013: 27]. Until now, in digital parametric modelling, architects relied on a graphical description of the design problem, which could be based on:

- the text method by programming or writing code using a specific programming language Textual Programming Language (TPL) [Janssen 2015: 157-158],
- visual programming consisting of manual manipulation of graphic elements,
- a declarative method using the Visual Programming Language (VPL) [Zhang, Zhang, Cao 2001: 186-200].

This meant that from the mathematical point of view, the programming language had to be at least complete in the Turing sense, but it could also be used to describe more limited languages. In any case, in order for a program written in a given language to be executed, it is necessary to properly process its source code.

Currently, a digital model of an object can be prepared on the basis of initial concepts generated in a 2D image from artificial intelligence-based systems. AI-based automation is used to create various types of materials and works from scratch based on so-called described prompts, which requires providing detailed parameters of

the generated images. While traditional AI is designed to analyze and predict based on existing data, generative AI goes a step further, giving the designer the ability to express and explore their creativity more effectively by creating new data that did not exist before.

As Patrick Schumacher, an architect at Zaha Hadid's office, points out, generative AI is particularly useful in the early stages of a project, greatly increasing creativity as well as productivity. The Zaha Hadid's team also uses AI-based image generators such as DALL-E 2 and Midjourney. Nonetheless, these are not generators that create a digital 3D model. Despite this obstacle, the experience with the use of artificial intelligence gathered during the research on the development of the Oceanarium concept in Szczecin shows that there is no problem in obtaining such a 3D model directly from the image in the non-linear dynamic processes of the Maya program. Consequently, it can be assumed that over time, the integration of AI with digital parametric modeling will increasingly become the next area of experimentation, but also of increasing design creativity, automating repetitive tasks and optimizing the entire design process, pushing the boundaries of what is possible.

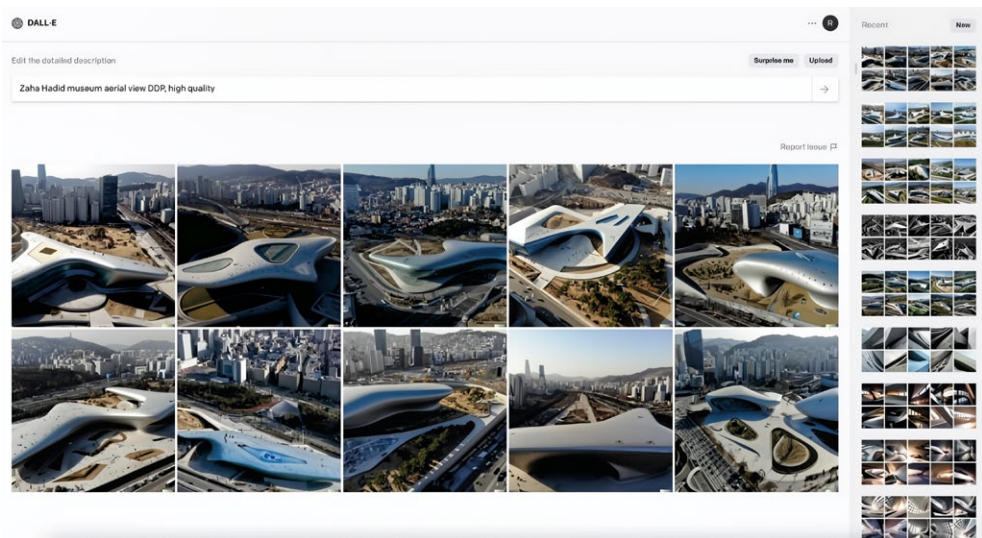


Fig. 1. Images generated on the basis of clues entered into the DALL-E 2 data generator [Schumacher 2023]

The creation of generative AI would not have been possible without generative competitive networks GAN, which were introduced by Ian Goodfellow in 2014. They consist of two neural networks, i.e. a generator and a discriminator that compete with each other to create realistic data by creating fake samples and recognizing the difference between real and digitally fabricated data. "The researchers

started training the network on low-resolution images and gradually increased it by adding successive layers. This incremental method allowed the learning process to first discover the large-scale structure of the image distribution, and then to pay attention to increasingly precise details in the image, instead of learning everything at once” [Mazurek 2019]. This allows you to obtain spectacular results and generate very realistic images.

In contrast, variational autoencoders VAE provide a probabilistic approach to data generation, enabling the creation of new data instances that did not exist before. Such a model is based on the principles of statistical inference, where the probability element of the data in the coding process. Transformers, such as those used in GPT-3 or GPT-4 models, have transformed natural language processing, enabling the generation of coherent and contextually relevant text from input data, which may include stories, articles, or other data expressed in writing.



Fig. 2. Images generated in cooperation with Stable Diffusion
[Schumacher 2023]

Architects are also developing their own AI tools. Zaha Hadid’s studio is going a step further and from 2023 has been developing its own versions of AI tools, with a specialized team of researchers working on the development of a system based on Stable Diffusion, an open-source system [Kietzmann 2023: 115-117]. This means that when individual versions or fragments of the project are created, screenshots are taken and in the iteration process developed in detail by AI and rendered. This approach generates satisfying results, and the longer you cooperate with a particular AI engine, the more tailored the results can be obtained.

4. BETWEEN AI IMAGE AESTHETICS, PARAMETRIC DESIGN AND STRUCTURAL-MATERIAL ASPECT. CASE STUDY

Virtual free surfaces that are created using parametric design supported by 2D images from artificial intelligence generators impose structural and material solutions that have not previously existed in architecture and construction. Exploring these relationships is a problem rarely undertaken by architects in Poland due to the complexity and difficulty of the issue, which requires excellent engineering preparation in terms of operating advanced computer programs.

The year-long cooperation with Midjourney, among others, to create the Oceanarium project as part of Jacek Czudak's master's thesis from 2024 allowed us to specify the style that corresponded to the author's perception of beauty and order. The synthesis of this style is inspired by organic forms, shapes present in nature, but above all by our own renders and print screens of free-form parametric models.

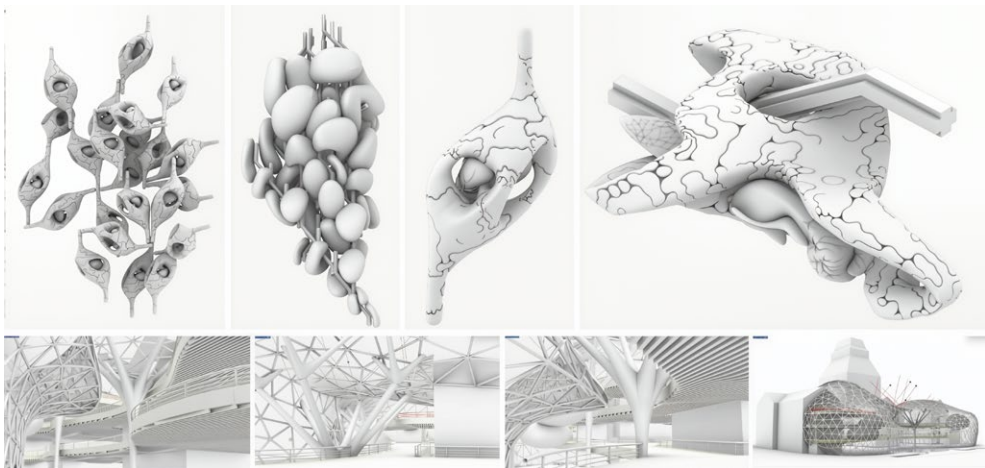


Fig. 3. Selected models made in Grasshopper, which were used as input data to obtain 2D images in the Midjourney generator [Czudak 2022]

There was a need for the sculptural envelope of the Oceanarium to be adapted to the needs resulting from the complex functional program of the object. A space with an internal landscape of free shapes and an external form of the facility were obtained, which are inextricably intertwined as in the baroque Leibnizian philosophy of monads popularized by the French philosopher Gilles Deleuze (1925-1995). Deleuze, in creating his own concept of being, claimed that architecture can be understood as a “skin of matter”, stretched on the immaterial organism of internal program events and through “windows to the outside” (understood as contact with the outside), responsive to the environment. This means continuity, and even Jeffrey

Krausse's transition from the concept of "costume architecture" to the concept of "skin architecture" with all the consequences of this procedure.

COMMAND STRUCTURE

EXAMPLE:

/imagine: <https://media.discordapp.net/attachments/> aquarium, located near water, architectural icon, inspired by organic shapes, parametric design, biomorphic forms, futuristic, realistic, 4K, architectural rendering, by Zaha Hadid design, --ar 3:4 --tile --no blur dof

DIAGRAM:

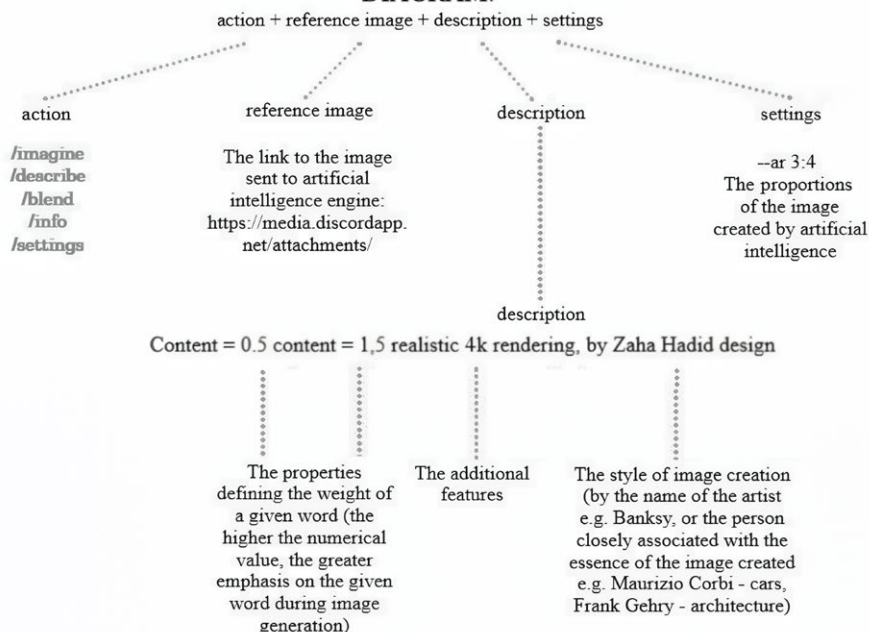


Fig. 4. Command structure in the Midjourney generator, developed as part of the diploma thesis prepared under the supervision of the promoter Karol Kowalski [Czudak 2023]

The main inspiration for the potential form was, therefore, the fluidity and this element referred directly to the law of continuity, the concept of folding, or curvature of Gottfried Leibnitz (1646-1716), the German mathematician and philosopher. The attempt to capture the movement and freedom that characterize non-linear liquid substances and transformation such a static frame into an architectural form is a process of understanding space that often goes beyond the bounds of imagination, and thus it is an extremely difficult element to define and present in a way that is understandable to artificial intelligence. Such a process requires a lot of time and numerous corrections in the structure of commands and other units of information, as well as countless

reiterations of results proposed by artificial intelligence containing numerous errors. Finally, after a trial period, the system assimilates the data, and on the basis of the analyses, it begins to understand what shapes and forms are involved. Thanks to this process of training the system, it was possible to generate fifty images of attractive architectural forms, which were used in the design process like classic sketches. The system was primarily trained on the basis of proprietary models, where renderings and screenshots of objects made by Jacek Czudak as the part of semester assignments at WA ZUT served as the “source” of inspiration for the Midjourney generator.



Fig. 5. Images created in the Midjourney generator, developed as part of the implementation of the diploma thesis prepared under the supervision of the promotor Karol Kowalski [Czudak 2023]

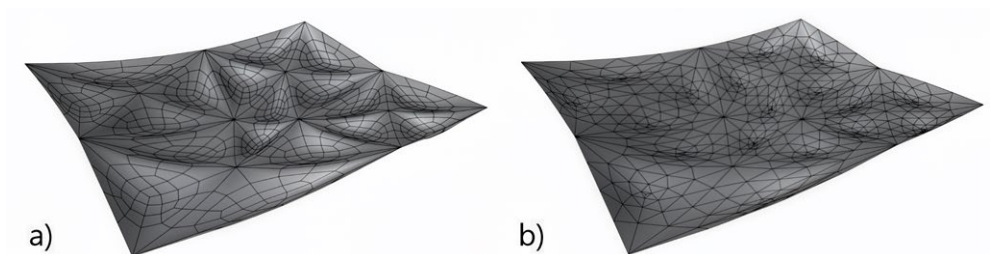


Fig. 6. Subsurface modeling in Weaverbird: a) surface liquefaction based on the Catmull-Clark algorithm, b) surface liquefaction based on the Loop algorithm [author's work]

The generated AI images were transferred to the 3D modeling phase, but it was noted that the simple freeform modeling strategies available in the basic Rhinoceros package could not be used to build the curved parametric surfaces. Therefore, tools such as Subdivision Surface Modeling (SubD), developed in 1978 by Edwin Catmull and Jim Clark for motion picture animation, and polygonal modelling were used for modelling. The shape of the surface is not defined here by mathematical curves, as is the case in NURBS surface modeling, but is the result of the density of the polygon. Polygonal elements per se do not store any geometrical information about the general shape of the object other than the information about the position of the vertices in the global XYZ coordinate system, which affect the shape of its geometry.



Fig. 7. Modelling method in nonlinear dynamic processes of the Maya program, developed as part of the diploma thesis prepared under the supervision of the promotor Karol Kowalski [Czudak 2023]

In the early phases of the Oceanarium project, where the definition of the shape was one of the main assumptions, the modeling methods were used in the non-linear dynamic processes of the Maya program. The decision to import the image geometry files into Maya was made due to the program's ability for 3D blending. The Quad Draw tool created the shape of this object in sequences of the same series of modifications, where individual elements of the shape were gradually developed. "The Quad Draw tool offers an enhanced, single-tool workflow for grid retopology. The manual retopology process allows you to create clean grids while maintaining the shape of the reference surface" [Autodesk Maya... 2024]. A precise model was obtained, which was then already prepared in the Rhinoceros environment and the parametric Grasshopper script. By using the Grasshopper plug-in called Weaverbird and Catmull Clark's command, the surface of a polygonal mesh was more fluid. The geometric properties of such a mesh remain unchanged under transformation and flexible topological deformation. The mesh topology is defined by a set of sequentially connected vertices that define the shape of a polygonal facet. The basic mesh is a single quadrangular or triangular facet with edges.

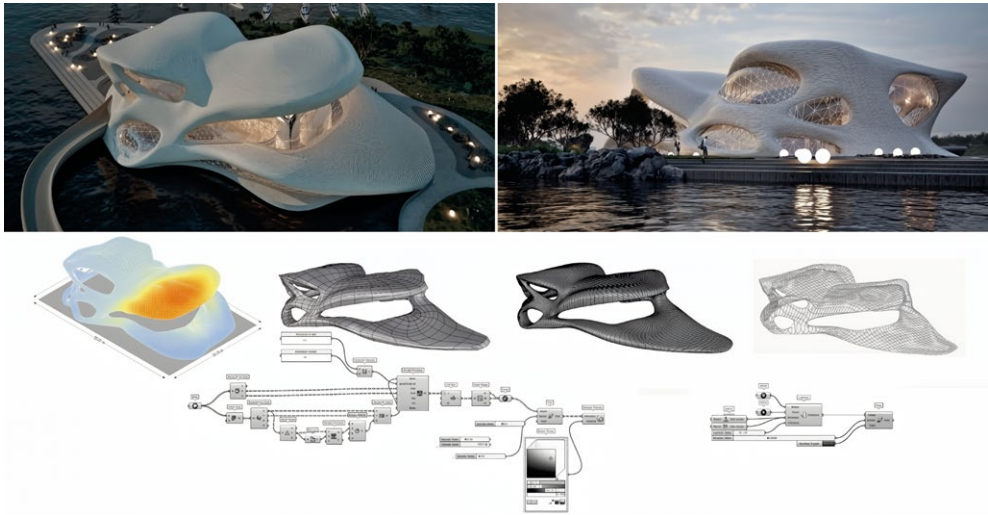


Fig. 8. Structural analysis of FEM in the Karamba overlay, liquefaction of the Oceanarium envelope surface in the Grasshopper program, developed as part of the diploma thesis prepared under the supervision of the promoter Karol Kowalski [Czudak 2024]

A similar approach was used in all aspects of the design in the Guangzhou Opera House (2005-2011), a project by Zaha Hadid's Architects. The external form was worked in Rhinoceros 3D software, while the interiors, with more complex and fluid surfaces, were developed in Maya software, while 2D drawings were done in AutoCAD software. Rhinoceros 3D software was used to model the NURBS surfaces of the opera house and the multi-functional performance hall. These surfaces were divided into triangular and quadrangular units, which facilitated the structural analysis of FEM, which is usually dependent on the discretization of the area into polygons.

The modeling in Rhinoceros 3D began with the general free-form modelling of the "stones", which were later translated into a combination of flat surfaces connected together using one of the digital tools to seamlessly round the two surfaces. Sap2000 Computers and Structures, Inc. (CSI) and the Ansys software were used to solve the opera's structural problems. A simple static system was used in the design of the structure, where the designers aimed to ensure that the steel joints between the curtain walls and the roof not only served a structural function, but also a static one, so that each steel section of the walls and the roof supported each other. Achieving this stability was possible only in a completely closed static system. In addition, modal analyses and seismic, wind and thermal simulations were performed using Sap2000 [Taiyun, Jiang 2010: 89-96].

Using this plugin, the Oceanarium's envelope was discretized using a flat panel mesh, which helped to solve complex structural dependencies – the finite element method. It should be emphasized that the mesh geometry was to reflect the visual quality of the form, where each steel element of the object's envelope had a unique combination of forces. The flow of such information in traditional documentation would require tens of thousands of drawings and at least as many pages of calculations. The MES calculations provided gave the answer in the form of designing two independent structures. The internal skeleton of the object was made, designed in a traditional structure of concrete ceiling slabs supported by HEB beams and reinforced concrete columns. On the other hand, the complex structure of the envelope was made in a steel structure. The spatial truss skeleton model was optimized, where, instead of a triangulated mesh, a double orthogonal mesh was chosen, where their cross elements of circular cross-sections are provided for welding. In this way, the structural capabilities of the two mesh layers were combined so that they work as one spatial structure with locally diverse behaviors.

One of the key areas where AI will have an increasing impact is the precise execution of manufacturing tasks. Digital manufacturing, also known as digital fabrication, is “a subcategory of computer-aided design and manufacturing (CAD/CAM) because it uses computer-controlled machines as tools to cut or create parts” [Ford 2016: 1].

Analysing the Oceanarium project in Szczecin also in terms of the manufacturing aspect of the construction envelope, it can be seen how complex, time-consuming and error-prone the digital fabrication stage could be, if it were based exclusively on digital parametric design techniques, which will not replace information-rich feedback in the workflows between factory, construction and interdisciplinary design processes.

The final stage of the Oceanarium's freeform modelling had to be developed in Rhinoceros/Grasshopper, where an accurate geometry of constant internal surfaces was generated. To verify the validity of the two-curved reference surface, Zebra analyses were performed to determine whether the roof curvature met G2 continuity. The data obtained made it possible to proceed to the phase of the facade design, which was to be solved by the use of bendable wood, whose trace follows spirally, emphasizing the form of the building. Based on a computationally efficient iterative rules system, each curved element of the wood cladding was modelled approximately to the surface geometry. The process by which high-quality façade cladding panels are obtained is based on algorithmic panelisation and optimization incorporated into a global script. As manufacturing processes become increasingly complex, such a process can now also be supported by artificial intelligence, which has the potential to revolutionise the manufacturing industry by increasing efficiency, reducing errors and developing innovations. In this way, by automating routine tasks, both production time and production costs are reduced. In addition, AI can analyze operational performance data in the production hall to identify potential problems before they change into costly processes.

5. CONCLUSIONS

At the current stage of development of artificial intelligence, identifying and interpreting its role in the architectural design process requires systematizing knowledge because; on the one hand, we have a fairly simple experience of changing the way of searching for architectural form in its early initiation stage. On the other hand, artificial intelligence in the third era of its development is implemented in CAD/CAM/CAE software programming languages, efficiently supporting users in specific decisions of the design process. The above experience is a description of the search for a form and all the consequences resulting from it. This practice is not conditioned by providing a large amount of information beyond defining inspiring patterns, images, forms, shapes, colors, textures. It is therefore a simple action, covering much less input data than the information that must be provided in the similar selection process of emerging a form modeled by digital parametric tools. Furthermore, to the geometric and spatial aspects, those related to structural and material activities, fabrication and assembly, and all the dependencies between them are also significant.

Despite the lack of a wide range of objective factors provided to AI generators, the assessment of the potential of artificial intelligence is promising. It provides us with output information in the form of an architectural concept obtained in real time, and is additionally distinguished by the multi-variant interpretation of text into an image. Nonetheless, it should be emphasized that in this multitude of obtained 2D images, we are dealing with a graphic declaration of the shape of a given object, which is not the parametric design, but it also does not exclude the use of digital parametric tools at later stages of the project, as long as the 2D image is converted into a 3D model. In the information space popularizing artificial intelligence, it is often mistakenly assumed that AI is currently able to autonomously design entire buildings in relation to forms with complex shapes. As can be seen from the current development of AI, this thesis is based only on the initial stage of emerging the architectural concept of the object, as already explained. The shape and features of such an object are subject to the need for constant validation based on a computationally efficient, iterative system of rules thanks to which multi-criteria analyses can be performed.

An additional conclusion that results from the use of AI illustrates that in freeform modelling, the use of basic strategies and methods available in Rhinoceros/Grasshopper based only on mathematically accurate NURBS geometry (Non-Uniform Rational B-spline) will be a constraint for designers (apart from the ease of use of simple tools of the aforementioned 3D modelers) in the initial phase of projects. Freeform surface modelers described by analytical functions that rationalize geometric elements will at certain initial stages of the project give way to subsurface modelers that are more capable of reflecting complex and intricate shapes. This is possible because objects generated by AI are forms with a strong effect that stand out from their surroundings in order to arouse strong aesthetic emotions. This is

about the ability of an object to evoke aesthetic experiences in the recipient, under appropriate conditions [Wallis 1968: 9]. This corresponds to the concept of the so-called aesthetic situation, in which the creator, the work and the recipient are united by aesthetic value [Gołaszewska 1970: 34].

In a short time, global trends of the future, which, among other things, shape society, the built environment and the profession of the designer, may lead to a more radical change in the architects' approach to computer-aided design processes. Looking at the development of AI in architectural design processes, a crucial role will be played here by machine learning algorithms, which also enable CAD systems to learn from user behavior, predict design preferences and offer intelligent suggestions, which is already happening in various industries such as medicine, chemistry and architecture, where artificial intelligence is slowly being implemented in BIM programming. The impact of AI-based automation and its practical implementation methods imply promising changes in the organization of design practice, but they may also lead to the trap of narrowly understood technological determinism at a rate that was not considered possible just a few years ago. As Antoine Picon notes, "technology is rarely the only explanation, especially in architecture, where so much depends on economic, social and cultural factors" [Picon 2010: 9].

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SZTUCZNA INTELIGENCJA I JEJ WPŁYW NA TRANSFORMACJĘ PRAKTYKI PROJEKTOWEJ NA PRZYKŁADZIE ARCHITEKTURY MODELOWANEJ PARAMETRYCZNIE. BADANIA Z WYKORZYSTANIEM GENERATORÓW MIDJOURNEY

Streszczenie

Sztuczna inteligencja (ang. *artificial intelligence* – AI) fundamentalnie zmieniła możliwości architektury. Technologia AI w swoich licznych przejawach jest uważana za oszczędzającą czas i zasoby, a ponadto zmienia sposób, w jaki robimy projekty. Na czele tej bezprecedensowej ewolucji stoi projektowanie parametryczne, które jest graficznym opisem problemu projektowego w sieci powiązań geometrycznych, które mogą być przetwarzane w różnych kontekstach przestrzennych. Od momentu, gdy międzybranżowy interfejs komunikacji został poszerzony o pierwsze zaawansowane programy modelowania parametrycznego 3D oraz BIM, minęły ponad trzy dekady. W tym czasie modelowanie cyfrowe zastępujące analogowy proces poszukiwania formy zostało ugruntowane w teorii architektury tysiącami publikacji i konferencji naukowych poświęconych tematyce CAD/CAM/CAE. Obecnie taką dziejotwórczą zmianę w podejściu do projektowania dostrzega się w sztucznej inteligencji, która jest dla architektów sposobem na szybkie generowanie atrakcyjnych wizualnie pomysłów, przede wszystkim dla obiektów o cechach formy swobodnej. W artykule przedstawiono badania zrealizowane z użyciem generatorów sztucznej inteligencji dla geometrycznie zaawansowanych form swobodnych uzyskiwanych w modelowaniu parametrycznym.

Słowa kluczowe: sztuczna inteligencja, uczenie maszynowe, projektowanie parametryczne, projektowanie cyfrowe, forma swobodna