Artificial Intelligence in Architecture: An Educational Perspective

Salih Ceylan[a]
Faculty of Architecture and Design, Bahçeşehir University, Ihlamur Yildiz Street No: 10, Beşiktaş, Istanbul, Turkey

Keywords: Artificial Intelligence, Architectural Design, Architectural Education, Architectural Representation.

Abstract: Artificial intelligence is a phenomenon that currently influences every aspect of life. AI applications already started to change the business methods in different disciplines. Architecture is one of the disciplines that is highly affected by the developments in AI technologies. The complex nature of the practice makes architecture a significant area of experiment for artificial intelligence applications. From building information modelling to advanced visualization techniques, artificial intelligence and architecture's collaboration has important outcomes that affect the practice's present and future. However, the permanent and more fundamental effects of AI on architecture must be followed in the architectural education curricula which provides the basics for the future of the profession. This paper presents a study that reviews the methods of artificial intelligence in architecture from an educational perspective. It includes existing implementations and potential future strategies from different domains and areas of theory and practice that might be useful for the development of architectural education.

1 INTRODUCTION

Artificial intelligence is one of the most popular fields of study in the 21st century. Although its hypothetical roots may be found in the ancient history, its real appearance in the world agenda was seen at the end of the 20th century. Various disciplines such as engineering, medicine, marketing, economy, etc. approach AI as a supporting and influencing force for their innovative work. It is clear that AI will somehow become a part of daily life in the future, but important is the question about which role it will play, and how AI systems and human civilization will coexist (Haenlein and Kaplan, 2019).

Artificial intelligence is defined as *a system's ability to interpret external data correctly, to learn from such data, and to use those learnings to achieve specific goals and tasks through flexible adaptation* (Kaplan and Haenlein, 2019). Obviously, the definition is based on the term "data". Therefore, AI is growing parallel to the developments in computing power and the amount of data stored in global resources. Every discipline is trying to utilize and interpret the data from its own perspective. AI makes self-driving cars, distant operations, image recognition, or smart homes possible through relevant algorithms. Consequently, one may assert that AI is a tool for any discipline to redefine itself.

Architecture is the discipline that is responsible for the design of all built environment. It provides an harmonic assembly of interdependent elements, so that it needs to make use of any possible support to improve itself, technology being one of them. Thanks to technology, design became a prescriptive activity, in which models and drawings are used to foresee reality, and in which everything must be resolved before the construction process (Celani, 2012). It also helps complex design objectives and forms to be fulfilled. To ensure that, architects utilize the opportunities given by artificial intelligence (Bhatt et al., 2016). Therefore, it is one of the disciplines that may redefine itself through the novelties brought by artificial intelligence. Accordingly, following questions emerge: How can architecture transform data and algorithms into useful instruments for the development of the practice? What are the methods that can be utilized for effective use of AI in architecture? How can AI become an essential part of architecture?

The answers for these questions partially lie under some existing and potential technologies such as BIM software, building physics analysis tools, and

[a] https://orcid.org/0000-0003-3808-7773

Ceylan, S.
Artificial Intelligence in Architecture: An Educational Perspective.
DOI: 10.5220/0010444501000107
In *Proceedings of the 13th International Conference on Computer Supported Education (CSEDU 2021) - Volume 1*, pages 100-107
ISBN: 978-989-758-502-9

parametric design interfaces. In addition to these and more importantly, for a permanent existence of AI in architecture discipline and a firm coordination between them, a fundamental understanding must be provided that considers AI as a basic and natural element of architectural education. Since the recent increasing computer-based applications, the future of architectural education has been at the forefront of architectural debate (Güney, 2014). This paper presents a study on the connection of AI and architecture, looking into their existing common points and potential collaboration options. In the focal point of the study there is architectural education and its various aspects from an open perspective for the influence of AI. The paper also presents in which domains of architectural education AI shall be integrated, and what kind of strategies must be followed for an effective implementation. The second chapter of the paper presents the existing relationship between the architecture practice and AI, as the third chapter is focused on the educational perspective of AI in architecture. Fourth chapter recommends strategies for the implementation of AI into architectural education curriculum, as the fifth and final chapter concludes the paper with discussions on positive and negative aspects of AI in architectural education and suggestions for future studies.

2 AI IN ARCHITECTURE

Walter Gropius (1970) asserted in his book *Scope of Total Architecture* that *good architecture should be a projection of life itself that implies an intimate knowledge of biological, social, technical, and artistic problems*. Based on this statement, it is obvious that architecture is a complex practice that needs to take various factors into consideration. In the pre-industrialization period, the amount of the data for the architects to deal with during the design and construction periods was within the limits for a human being to process; mostly based on user needs, local considerations, and construction methods. However, in the 20th century, due to globalization and the developments in the computational technologies, the amount of data to deal with has increased drastically. Cristopher Alexander (1964) stated more and more problems are reaching insoluble levels of complexity and at the same time they also change faster than before, so that new approaches including technological solutions need to be employed in architecture. Accordingly, attempts to combine computers and architecture increased in the second half of the 20th century. As the process of employing computational technologies with architectural purposes accelerated, the amount of data to deal with also increased proportionally. The amount of data produced globally between 2010 and 2019 raised from 2 to 41 zettabytes, more than 20 times; and it is projected it will raise up to 150 zettabytes, another 4 times in the next 5 years (Holst, 2020). A significant portion of this data is about built environment and human activities which are areas of interest for architecture. Consequently, architecture is in desperate need of support from computational technologies and artificial intelligent.

The contribution of artificial intelligence on architecture can appear on different aspects. Firstly, AI provides architecture an enormous amount of data and processing speed to create analytical information that have significant influence on decisions in any phase of design. Secondly, computer-aided design (CAD) programs and algorithmic or parametric design tools can generate forms that could not exist without computation (Steenson, 2018). Moreover, AI makes fast, effective, and alternative methods for visualization and prototype production possible. Building information modelling (BIM) software aid architects to handle design and construction stages as a holistic process. Finally, AI also augments architecture in the production phases with automated construction opportunities. Next chapter of this paper presents the ways of AI influencing architecture from its different aspects and in different phases of design and construction.

2.1 Data Collection and Processing

AI is all about data processing and it has reached an enormous amount and speed nowadays. Accordingly, architecture practice gets its share from this development. For the initial phases of design, there is a big amount of data for the architects to process: Legal codes, physical environment analysis, user's needs, functional requirements, previous cases, etc. These are all about data that needs to be processed. AI provides significant support dealing with all this data that may be impossible to process without the contribution of computational technologies. Additionally, reducing the time for indexing and classification of information required for the starting phases of design has an unnoticed but important effect on the design process.

2.2 AI to Create Design Options

Commercial software on the use of AI in architecture have reached an advanced level already. Some of the products work as standalone software as others function as plugins in other more advanced programs. One of them, *Dynamo* is a plugin for Revit and enables users to use Virtual Programming to process data and compose custom algorithms (Mousiadis and Mengana, 2016). It gives the user the ability to automate processes with the logic of a graphic algorithm editor (Sandzhiev et al., 2018). Likewise, *CATIA*, which stands for *Computer Aided Three-Dimensional Interactive Application*, was first produced in 1977 and is still being used as an algorithmic design application. It proves the relevance and coherence of the new technologies, materials, machinery, progressive methods and information tools that enable more efficient use materials (Dubovska et al., 2014). The software is being used by famous architectural offices worldwide. Another one is the graphical parametric form generationg tool *Grasshopper,* which works under *Rhinoceros.* It is being used in different scales and aspects of design. For instance, Schneider and his colleagues (2011) utilized Grasshopper for the development of an urban design proposal at a teaching exercise.

In addition to the products already in the market, researchers and academics keep studying on the methods to combine AI and architecture with each other in terms of design development (Marson and Musse, 2010; Mohammadi et al., 2018; Ahmed et al., 2012; Jabi et al., 2017). For instance, Chaillou (2019) applies AI to floor plan analysis and generation with the three-fold aim of generating floor plans, qualifying them, and to allow users to browse through the options. Another important example of studies is the *Project Discover*, which is an application of generative design for space planning (Nagy et al., 2017). Another one is *DANIEL,* a deep architecture for automatic analysis and retrieval of building floor plans (Sharma et al., 2017). In another study, As et al. (2018) demonstrate how to use generative adversarial networks (GANs) to generate unique and original design variations.

2.3 Building Information Modelling

Building information modelling (BIM) is one of the most popular terms in the world of contemporary architecture. BIM is also a ground-breaking development as it is a multidisciplinary approach and contributes to strengthen the relationship between different participants of the construction industry such as architects, engineers, and contractors. According to Eastman et al. (2008), BIM is not only a technology change but also a process change. Main aims of BIM are; to decrease project cost, increase productivity and quality, and reduce project delivery time (Azhar, 2011). The term BIM refers to a simulation of the building design in virtual environment. The resulting model, a Building Information Model, is a data-rich, object-oriented, intelligent and parametric digital representation of the facility, from which views and data appropriate to various users' needs can be extracted and analysed to generate information that can be used to make decisions and to improve the process of delivering the facility (Azhar et al., 2008). Therefore, regarding the extreme complexity of the multi-layered and multi-disciplinary structure of BIM software, AI has to be its backbone.

2.4 Building Performance Analysis

Building performance analysis refers to the process where the building's behaviour under certain effects is inspected. It is not a new term, but with the support of AI and BIM, it has become easier to conduct, more reliable, and reproducible. Nowadays, software or plugins specialized in performance analysis are being used through interoperable processes with BIM software for more effective and productive results. Two main types of building performance analysis come forward: energy performance and structural performance. Both are important from different perspectives. The next subchapters of the paper are about the two types of analysis made possible using AI.

2.4.1 Energy Performance Analysis

Energy performance analysis (EPA) can be conducted on various areas of a building with different focal points such as visual and thermal comfort on façade of buildings (Naboni, 2014; Marroquin et al., 2014). Software for EPA are evaluated through following criteria: Usability and information management of interface, integration of intelligent design knowledge-base, interoperability of building modelling, and the accuracy of the tool and its ability to simulate complex and detailed building components (Attia et al., 2009). Currently, there are many EPA tools that are accessible such as *Ladybug, Honeybee, Geco, and Heliotrope-Solar.* They mostly operate as plugins under other software. For instance, *Ladybug* is a tool to work in collaboration with Grasshopper, with an effort to support the full range of environmental analysis in a single parametric platform (Roudsari and Pak, 2013).

2.4.2 Structural Performance Analysis

Structural performance analysis is a domain in the intersection of architecture and engineering. It is an extremely important issue and its training is sophisticated and interdisciplinary. Therefore, its education must be given properly to avoid disasters caused by wrong or poorly executed structures in the future.

2.5 AI in Architectural Representation

Representation has been a part of architectural design since the first days of the practice. Nowadays, in CAD applications, every design tool has an interface for representation. However, representation has gone to a very advanced level under the influence of computational technologies and AI, providing alternative media for visualization. s an important means of architectural expression, the virtual technology of architectural animation provides a new digital mode for the promotion of architectural image (Yang, 2020). There are software and tools that provide a high quality of visual products with the help of AI, such as *Vray* which works under several different programs. Additionally, some software *Lumion, Twinmotion,* and *Cinema4d* make animations with realistic renderings very easy to produce and edit. Dounas (2020) sees animation as a computational understanding of architectural design. With the software, it is even possible to simulate the appearance of the architectural product under different weather conditions like snow or rain.

Another novel representation method emerged with virtual reality (VR) and augmented reality (AR) in architecture as interactive techniques. Interactive visualization of architecture provides a way to see current, as well as future stances of buildings (Aliaga,2007). Some existing programs added AR or VR options to its visualization methods through plugins like *Enscape* or *VRSketch*, as some other software such as *EyecadVR and IrisVR* completely focus on VR experience as a representation method for architectural products.

2.6 AI in Construction

Construction industry has evolved from traditional to modern methods of construction (Rohani et al., 2014). Therefore, it could use the support of AI effectively through collaboration with robotics, BIM and AR technologies. One of the ways AI supports construction is mostly using additive manufacturing. Additive manufacturing or 3dprinting nowadays is a novel but effective way of constructing buildings. It was in the past an expensive process, but recently it has become one of the most cheap, affordable, and eco-friendly ways of constructing buildings (Mathur, 2016). Additionally, automation is an important innovation in construction. Systems like automated building construction, shuttrise, and steel frame remote releasing are examples of automated construction (Maeda, 2005). According to Wang and Love (2012) industrialization of the construction process requires a high level of automation, which happens to the site work tasks that require high integration of information and physical intensive resources.

3 AI IN ARCHITECTURAL EDUCATION

Architectural education forms the basis of the practice. Therefore, it must be up to date regarding the developments and requirements in the field of architecture. As the architecture profession is under the strong influence of technological developments, its education should also be following them and update itself accordingly. Accordingly, artificial intelligence as an effective factor in architecture needs to be a part of architectural education. However, as mentioned in the previous chapters, architecture and AI have a multifaceted and complicated relationship. Additionally, architectural education has a very complex and dynamic structure. Therefore, the implementation of AI into architectural education needs a systematic approach. Various researchers and educators have begun to address the need to integrate digital design in architectural design education (Oxman, 2008). The need must be well defined and met with a holistic organization that handles the whole architectural education curriculum.

AI tools are already implemented in many parts of educational process including content development, teaching methods, student assessment, and communication between teacher and students (Chassignol et al., 2018). However, especially for architectural education more effective actions are required. Implementation of AI into architectural education is also important for stronger and healthier relationship between architecture and AI. Architectural education as the foundation of the profession is responsible for equipping young architects with proper tools to tackle emerging problems of society (Ceylan, 2020). If the upcoming generations of architects are aware of the opportunities provided by and well equipped with the skills to utilize AI in the design and construction processes; they will contribute to the relationship between the profession and AI. The next chapters of the paper examine possible strategies and methods for the implementation of AI into architectural education.

3.1 Strategies for the Implementation of AI into Architectural Education

Architectural education has a complex structure with various modules. Every module has a different purpose and characteristics. In the core of the education there is the design studio. All other courses' knowledge is conveyed on the design studio where the students can reflect their educational gains and improve their design skills. The architectural curriculum is composed of fundamental courses that develop design knowledge; courses that develop the scientific formation of architecture; courses for strengthening architectural representation; and design courses, a combination of the others and constitute the most crucial part of design education (Demirbaş & Demirkan, 2003). In this paper, this four-fold definition of architectural education is used as the basis of the proposed strategies.

The complex structure of architectural education together with the multi-layered influence of AI on architecture requires a holistic and well-organized approach for the implementation of AI into architectural education. Three modules of education; theory, technical, and representation modules, in addition to the design studio must be considered separately in detail, but at the same time in harmony with each other. The next subchapters present the strategies and methods for the implementation of AI into each module of architectural education.

3.1.1 Theory Module

Theory module in the architectural education curriculum is the part where the intellectual foundations of architecture students' knowledge are laid. It mostly consists of courses for the history of architecture, architectural theories, and some courses about legal and ethical aspects of architecture. At the same time, it is the least affected module by the developments in AI technologies for now. However, there is still some potential contribution of AI for the theoretical courses by providing data collection, storage, and processing. The lectures in the theoretical courses can use information from the architecture history, sample cases, and literature review organized and indexed with AI tools. Educators or students can choose from previously composed information whichever is more useful and necessary for them.

However, in the future the effect of AI on theoretical courses might be much more significant. It would be possible that the theoretical classes are given by AI sources, without the need to human lecturers. Information stored in the database can be organized and presented to the students through an interface that works automatically. Thus, regarding theoretical courses, someday, AI may be able to do all the work a lecturer can do.

3.1.2 Technical Module

Courses in the technical module equip architecture students with the knowledge and skills that they need to practice the profession. Building materials and methods, structure, environmental control systems, professional practice, and conservation are among the courses taught in this module.

AI can influence the courses in this module most effectively through BIM software and building performance analysis tools. Additionally, mapping and photogrammetry software like *Pix4d* or similar tools can be used to perform photogrammetric processing of digital images to generate 3D spatial data for construction and conservation purposes.

One of the biggest benefits that BIM tools can provide for the students of architecture is that they can introduce building elements effectively through their continuously evolving and expanding libraries. Thousands of elements in the library are ready for the use and examination of the students in their studio or homework. Additionally, BIM software can also help teaching the student how to use information in an effective way without getting into too many details by only knowing how information is accessible.

Building performance analysis tools can also be beneficial for the students, especially by raising awareness among them on the importance of a building's energy and structural performance. Students who can access energy and structural performance information of buildings quickly with the support of AI may become eager to get further and obtain more important and useful information on how to make it even more energy efficient or more resilient.

The benefits of BIM and other AI applications in technical module of architectural education increases when they are successfully connected with other modules of education, especially representation module and the design studio.

3.1.3 Representation Module

The representation module is the place where students are introduced to various methods to reflect their design ideas on different media. It is the module that might potentially be the most affected by the developments in AI technologies. With the support of AI, courses for representation methods in architecture may become something more than only teaching how to use digital technologies and computers as drafting tools, they may become real design instruments. According to Chaillou (2019), *the machine, once the extension of our pencil, can today be leveraged to map architectural knowledge, and trained to assist us in creating viable design options.* Courses in the representation module of architectural education are the most suitable place for this paradigm shift to happen.

Parametric and algorithmic design is already on the agenda of architecture and it has somewhat a place in the architectural education curriculum. However, the attempts to put these emerging design tools are based on the personal efforts and dedication of educators and students. An institutional approach is needed for these methods to be effective parts of the curriculum. Parametric and algorithmic design methods that are influenced by AI need to be compulsory rather than elective courses for every student to be aware of the importance of these design methods. Being proficient to use these tools, students may direct their energy and interest to more effective aspects of design.

Additionally, AI also affects representation through novel methods like VR, AR, and 3d printing. Students need to be aware of these methods for digital communication to create more impressive presentations. Alternative realities also help students to experience their designs in 1 to 1 scale and more intimately, so that they can initialize their design approach better. 3d printing tools help students with their physical models by enabling them to bravely try complex forms without the suspicion to materialize the physical model.

In brief, AI may have revolutionary effects on the representation module of architectural education if implemented properly. A holistic model needs to be applied for all the tools to function in harmony and be beneficial for the students. The place where the proposed methods and strategies can be tested is the design studio as it is in the centre of architectural education.

3.1.4 Design Studio

Design studio is the core of architectural education. It is the place where all theoretical and technical knowledge come together in exercises for the development of students' design skills. In the design studio, students learn a new language, new skills like visualization and representation, and architectural thinking as different aspects of design education (Ledewitz, 1985). Accordingly, it is the place where the effects of AI on architectural education curriculum can be recognized most evidently.

All stages of design in the studio may be supported by AI in various ways: In the starting phases where the student research about the given subject, they can benefit from AI in terms of data processing and indexing of research objects. They can explore databases to find relevant information for their design subject. Likewise, they can use similar methods in the environmental analysis phase. In the preliminary design phase, they can use parametric design or algorithmic design tools for layout decisions or façade design. In the following phases, when they have some design proposals already, they can use building performance analysis tools to see how their proposed buildings perform in terms of energy efficiency and structure. They can also benefit from VR environment to experience their design in full scale and free from the rules of the physical world and use alternative realities for the presentation of their ideas. 3d printing tools can be utilized when making physical models for more precise products, even if they have a complex form. Thus, AI can touch a student's design journey in the studio from multiple aspects through various instruments. This gives the student the opportunity to focus on more important points in design for more successful design process, as well as final products.

4 CONCLUSIONS

The connection between AI and architecture is undeniable. Many different fields of work prove that AI has a lot to offer for architecture. If architects can use the opportunity to utilize AI in various phases of design and construction, the nature of the profession will change irreversibly. The advent of AI in Architecture is still in its early days but offers promising results (Chaillou, 2019). However, nowadays it is too early to speak about a fundamental change because the relationship between AI and architecture is superficial; it does not come from the ground. For a stronger relationship and change in the basic understanding of the profession, the form of architectural education needs to be calibrated towards the utilization of AI. However, the road is long, and educators must progress carefully so that the process of the implementation works properly. Rather than personal and discontinued efforts, a holistic and systematic approach is needed.

Architects and architecture students need to remember that except its advanced levels of complexity and numerous alternatives it offers, AI is still a tool for design and the architect is the designer. It only processes the data according to defined algorithms. AI does not understand context, or design in historical context is an overcomplicated issue for AI. Human mind is still the final decision maker for design issues. Creativity and intuition remain as genuine features of the human mind. Designers must learn how to utilize AI tools rather than considering them as the main actors of design.

The relationship between AI and architecture is very strong. The educational aspects are also very important and complicated. For more concrete results and proposals for future changes in architectural education towards the use of AI, more scientific research with statistical outcomes, as well as case studies must be conducted. The future holds great potential for AI and architecture collaboration if it is managed properly.

REFERENCES

Ahmed, S., Liwicki, M., Weber, M., Dengel, A., 2012. “Automatic Room Detection and Room Labeling from Architectural Floor Plans”, IAPR International Workshop on Document Analysis Systems, 339-343. https://doi.org/10.1109/DAS.2012.22.

Aliaga, D.G., Rosen, P.A., Bekins, D.R., 2007. ”Style Grammars for Intearctive Visualization of Architecture”, Ieee Transactions on Visualization and Computer Graphics, 13(4):786-797.

As, I., Pal, S., Basu, P., 2018. “Artificial intelligence in architecture: Generating conceptual design via deep learning”, *International Journal of Architectural Computing*, Vol. 16(4) 306–327. https://doi.org/10.1177/1478077118800982.

Attia, S., Beltran, L., De Herde, A., Hensen, J., 2009. “Architect Friendly: A Comparison of Ten Different Building Performance Simulation Tools”, Eleventh International IBPSA Conference, Glasgow, Scotland, 204-211.

Azhar, S., Hein, M., and Sketo, B. 2008. “Building information modeling: Benefits, risks and challenges.” Proc., 44th Associated Schools of Construction National Conference, Auburn, AL.

Azhar, S., 2011. “Building Information Modeling (BIM): Trends, Benefits, Risks, and Challenges for the AEC Industry”, Leadership in Management and Engineering, 11(3): 241-252.

Bhatt, M., Suchan, J., Schultz, C., Kondyli, V., Goyal, S., 2016. “Artificial Intelligence for Predictive and Evidence Based Architecture Design”. In *Proceedings of the Thirtieth AAAI Conference on Artificial Intelligence AAAI-16*, 4349-4350.

Celani, G., 2012. Digital Fabrication Laboratories: Pedagogy and Impacts on Architectural Education. *Nexus Network Journal,* 14(3): 469–482. http://dx.doi.org/10.1007/s00004-012-0119-3.

Chaillou, S., 2019. “AI+Architecture: Towards a New Approach”, PhD Thesis, Harvard Graduate School of Design.

Chassignol, M., Khoroshavin, A., Klimova, A., Bilyatdinova, A., 2018. “Artificial Intelligence Trends in Education: A Narrative Overview”, Procedia Computer Science 136: 16–24. https://doi.org/10.1016/j.procs.2018.08.233.

Ceylan, S., 2020. “Using Virtual Reality to Improve Visual Recognition Skills of First Year Architecture Students: A Comparative Study”, Proceedings of CSEDU2020, 12th International Conference on Computer Supported Education, volume 2, 54-63.

Demirbaş, O. O., & Demirkan, H., 2003. Focus on architectural design process through learning styles. *Design Studies*, 24(5), 437-456. http://dx.doi.org/10.1016/S0142-694X(03)00013-9.

Dounas, T., 2020. “Animation as a computational framework for architectural design composition”, *Architectural Science Review*, 63:2, 222-232, https://doi.org/10.1080/00038628.2019.1709037.

Dubovska, R., Jambor, J., Majerik, J., 2014. Implementation of CAD/CAM system CATIA V5 in Simulation of CNC Machining Process, Procedia Engineering 69: 638 – 645. https://doi.org/10.1016/j.proeng.2014.03.037.

Eastman, C., Teicholz, P., Sacks, R., and Liston, K. 2008. *BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors*, Wiley, New York.

Gropius W., 1970. *Scope of total architecture*. Collier Books, New York.

Güney, D., 2015. “The importance of computer-aided courses in architectural education”. *Procedia - Social and Behavioral Sciences,* 176(2015): 757 – 765.

Haenlein, M., Kaplan, A., 2019. “A Brief History of Artificial Intelligence: On the Past, Present, and Future of Artificial Intelligence”. *California Management Review*, 61(4) 5–14.

Holst, A., 2020. “Volume of data/information created, captured, copied, and consumed worldwide from 2010 to 2024”, Statista. https://www.statista.com/statistics/871513/worldwide-data-created/, accessed 09.12.2020.

Jabi, W., Soe, S., Theobald, P., Aish, R., Lannon, S., 2017. “Enhancing parametric design through non-manifold topology”, *Design Studies,* 52, 96-114.

Kaplan, A.M., and Haenlein, M., 2019. “Siri, Siri, in My Hand: Who’s the Fairest in the Land? On the Interpretations, Illustrations, and Implications of Artificial Intelligence”, *Business Horizons*, 62(1): 15-25.

Ledewitz, S. 1985, “Models of design in studio teaching”, *Journal of Architectural Education*, Vol. 38 No. 2, pp. 2-8, https://doi.org/10.2307/1424811.

Maeda, J., 2005. "Current Research and Development and Approach to Future Automated Construction in Japan", Construction Research Congress, San Diego, California. https://doi.org/10.1061/40754(183)39.

Marroquin, H., Thitisawat, M., Vermisso, E., 2014. "Performative Parametric Design of Radiation Responsive Screens", ARCC Conference Repository. https://doi.org/10.17831/rep:arcc%y221.

Marson, F., Musse, S.R., 2010. “Automatic Real-Time Generation of Floor Plans Based on Squarified Treemaps Algorithm”, International Journal of Computer Games Technology, 2010, https://doi.org/10.1155/2010/624817.

Mathur, R., 2015. “3d Printing in Architecture”, International Journal of Innovative Science, Engineering & Technology, 3(7): 583-591.

Mohammadi, M., Al-Fuqaha, A., Oh, J.S., 2018. ” Path Planning in Support of Smart Mobility Applications using Generative Adversarial Networks”, 2018 IEEE Confs on Internet of Things, Green Computing and Communications, Cyber, Physical and Social Computing, Smart Data, Blockchain, Computer and Information Technology, Congress on Cybermatics, 878-885. https://doi.org/10.1109/Cybermatics_2018.2018.00168

Mousiadis, T., Mengana, S., 2016. “Parametric BIM: Energy Performance Analysis Using Dynamo for Revit”, Master thesis for KTH Royal Institute of Technology.

Naboni, E., 2014. “Integration of Outdoor Thermal and Visual Comfort in Parametric Design", 30th International Plea Conference 16-18 December 2014, CEPT University, Ahmedabad.

Nagy, D., Damon Lau, John Locke, Jim Stoddart, Lorenzo Villaggi, Ray Wang, Dale Zhao and David Benjamin, 2017. “Project Discover: An Application of Generative Design for Architectural Space Planning”, Proceedings of the Symposium on Simulation for Architecture and Urban Design, 59-66.Sandzhiev, N.V., Lalin, V.V., Savchenko, A.V., Serduikov, D.A., 2018. “Dynamo platform for automation Revit”, *Alfabuild*, 6(7): 75-82.

Oxman, R., 2008. Digital architecture as a challenge for design pedagogy: theory, knowledge, models and medium. *Design Studies,* 29(2): 99–120.

Rohani, M., Fan, M., Yu, C., 2014. "Advanced visualization and simulation techniques for modern construction management", Indoor and Built Environment, 23(5): 665-674. https://doi.org/10.1177/1420326X13498400.

Roudsari, M.S., Pak, M., 2013. "Ladybug: A Parametric Environmental Plugin for Grasshopper to Help Designers Create an Environmentally-Conscious Design", Proceedings of BS2013: 13th Conference of International Building Performance Simulation Association, Chambery, France, 3128-3135.

Schneider, C., Koltsova, A., Schmitt, G., 2011. “Components for parametric urban design in Grasshopper from street network to building geometry”, Proceedings of the 2011 Symposium on Simulation for Architecture and Urban Design, 68-75.

Sharma, D., Gupta, N., Chattopadhyay, C., Mehta, S., 2017. “DANIEL: A Deep Architecture for Automatic Analysis and Retrieval of Building Floor Plans”, 2017 14th IAPR International Conference on Document Analysis and Recognition, 420-425.

Steenson, M.W., 2018. “Why Architecture and Artificial Intelligence?”, XRDS: Crossroads, The ACM Magazine for Students, 24(3): 16-19. https://doi.org/10.1145/3187013.

Wang, X., Love, P.E.D., 2012. “BIM + AR: Onsite Information Sharing and Communication via Advanced Visualization", Proceedings of the 2012 IEEE 16th International Conference on Computer Supported Cooperative Work in Design, 850-855.

Yang, H., 2020. Architectural Roaming Animation Based on VR Technology. In: MacIntyre J., Zhao J., Ma X. (eds) The 2020 International Conference on Machine Learning and Big Data Analytics for IoT Security and Privacy. SPIOT 2020. Advances in Intelligent Systems and Computing, vol 1283. Springer, Cham. https://doi.org/10.1007/978-3-030-62746-1_55.