Title: Artificial Intelligence for sustainable architecture and design

Author: Annalisa Lanza Volpe

Source: Forum A+P 28 | Scientific Paper

ISSN: 2227-7994

DOI: 10.37199/F40002812

Publisher: POLIS University Press

Artificial Intelligence for sustainable architecture and design

ANNALISA LANZA VOLPE

Lindner SE I EPI (Entwicker. Planer. Ingenieure),Arnstorf, Germany

Abstract

The selection and implementation of appropriate design strategies need a careful evaluation to actionably reduce the built environment's impact on climate change. Planning for sustainable architecture and design is a challenge that requires collaboration and integrated solutions in many different disciplines. Software and tools can offer a significant support. In particular the use of artificial intelligence (AI) can change the work's method. The aim of this article is to analyse software possibilities in developing sustainable buildings..

Keywords: Architecture, Design, Sustainability, Artificial Intelligence (AI), Generative Design, Building Information Modelling (BIM), Life Cycle Assessment (LCA).

Introduction

The first section of the article summarizes what is AI. The next section focuses on its use in architecture and design and the last section discusses how its application can reshape architecture and design for sustainability.

What is Artificial Intelligence (AI)

The etymology of the word intelligence can help understand the meaning. It derives from Latin ***intellĭgentĭa,*** which comes from the verb ***intelligĕre,*** assimilated form of ***inter***, "between" and ***legere***, "choose, pick out, read" in the sense of select the relevant information. The intelligent person takes only the things that are important, puts them together and solves an arbitrary problem with them. There are three modes of thinking: convergent, divergent and lateral. While convergent thinking means to give the "correct" answer using logic, divergent thinking means to draw unexpected connections using imagination. Lateral thinking is using both, convergent and divergent thinking. It means thinking "out of the box", away from common solutions and concepts. A key characteristic of human intelligence is the ability to have convergent, divergent and lateral thinking. Artificial Intelligence (AI) is a branch of computer science concerned with creating machines that can simulate human intelligence characteristics and extend the cognitive experience through multiple technical devices [1]. AI is based on algorithms that tell the computer how to learn to operate on its own. The algorithms are developed with different goals and methods. They can focus on skills that include learning, reasoning, self-correction and creativity. In general, AI systems analyse large amounts of data, aiming to identify patterns and internal relationships that enable the generation of predictions. Today AI is a precious technology in many sectors because it allows machines to perform tasks typical of human operators, and often, thanks to the superior computing power of devices, even faster and with a lower error rate. AI is an ever-growing and improving technology that can benefit several

Figure 1: Image generated by the architect Andrew Kudless on Midjourney.

Figure 2-3: Images generated on Stable Diffusion Playground, just entering the key words "Zaha Hadid, museum, aerial view, mountains".

working sectors [2]. The integration of AI in architecture is dependent on the uniqueness of ideational thought, oriented to problem-solving and to responsive, self-regulatory and adaptive processes [1]. Today AI tools can actively assist designers and engineers in developing projects and improving performance. Complex topics like sustainability can be solved and we can expect to see continued advancements in sustainable, resilient and energy-efficient buildings.

Use of AI in architecture and design

Image Generator. In the past year, numerous technology companies have released software that uses AI systems to convert users text inputs into AI-generated images (Fig. 1). Tools like DALL-E 2, Midjourney and Stable Diffusion can take text descriptions and create realistic images. AI enables architects to quickly generate different visuals with only a text or a keyword input [3]. This is why this technology can be very helpful in the early stages of the project. Also Zaha Hadid Architects are using AI text-to-image generators to come up with design ideas for projects. The studio principal Patrik Schumacher presented an extensive catalogue of imaginary buildings created using tools bearing the studio's signature fluid, sinewy style made famous by its founder [4]. With AI tools everybody can create images for example by focusing on one architect or style. It's sufficient to enter a prompt or few key words, for example "Zaha Hadid, museum, aerial view, mountain" and click the generate button. In a few seconds different images will be displayed (Fig. 2, Fig. 3).

AI-generated images are pretty interesting since they combine the identity elements with a certain level of non-definition, resulting in a set of "engaging, semi-abstract visual prompts" that can inspire designers [2].

Augmented Reality (AR). AI can work also in combination with Augmented Reality (AR), a technology that enables users to visualize designs in real-time environments virtually. AR allows architects to immerse themselves in their creations and gain better insight into how they will look once constructed [3]. Augmented reality includes virtual elements that interact with what already exists. It is thus possible to combine virtual architectural designs with the reality of the construction site. For this, 3D plans and virtual model holograms are used to improve the understanding of the project and facilitate their execution. During construction, the ability to see through walls and understand the path of the technical installations facilitates the process, reduces the possibility of errors, and even guides the construction of complex geometries [5]. AI software tools enable machines to adjust to new inputs, learn from experiences and even perform human-like tasks [6].

Generative design. One way AI is used in architecture is through generative design. Generative design is a methodology that automates the creation of design options based on a set of constraints given by the architect [6]. Design can then be optimized for specific goals such as energy efficiency or material usage. This allows architects to consider more options than they would be able to manually. AI generative design tools used in architecture are Maket.ai, Arkdesign.ai, Spacemaker and a few others. Maket.ai and ArkDesign.ai are AI-based software specifically created for architectural designers looking to generate plans instantly based on their client's needs and environmental constraints. Users can generate detailed floor plans based on profitability, space utilization, energy efficiency and more. Spacemaker is a cloud-based AI software that empowers architects, urban planners, and developers to make smarter decisions faster. With Spacemaker, architecture teams can quickly test out different designs in order to identify the best projects. By using Spacemaker's predictive analytics capabilities, architects are able to optimize their projects' performance across various criteria such as energy efficiency or cost savings without sacrificing quality or design creativity [3]. Generative AI is not a new technology. Its history dates to the 1950s and 1960s. There are papers in the 1970s that

Figure 4 - 5: Kartell first chair designed with artificial intelligence.

demonstrate how people were really thinking about, in architecture and specifically in hospital floor plans, how to lay out those floor plans algorithmically [7]. With CAD-based version of generative design, the application of algorithms is automated, but the designer has to evaluate the computer generated results and decide on the most suitable option. The latest wave of generative design is driven by AI software that uses algorithms that mimic the Darwinian evolution. After a number of iterations, different solutions are evaluated and the highest-scoring design is chosen [8].

NASA used an evolutionary AI software to create configurations for its evolved antenna of a 2006 mission called Space Technology 5 (ST5). Engineers settled the performance and the computer started with random designs and through the evolutionary process, refined them, keeping the best antenna designs that approached what they asked for. The final design performed more than 90% more efficiently over the traditional antenna. In the NASA example we can see how AI can enhance

Figure 6: Casa Batlló (Antoni Gaudi), Barcelona, Spain.

creative decisions by introducing options that humans may not even initially consider, with effective results [7]. The designer first decides on the constraints and objectives of the final design. After that, AI guides to the best solutions that satisfy the prefixed goals. During Milan Design Week 2019, the Italian brand Kartell has displayed the first chair designed using artificial intelligence, now available worldwide (Fig. 4, Fig. 5). The chair was designed by Philippe Starck using a prototype generative design software developed by Autodesk. The AI created a chair model using an algorithm that respects the original brief, a comfortable seat that has the structural strength and solidity requirements to ensure certification and respect aesthetic standards of simplicity and clean lines [9].

Generative design allows architects, engineers and manufacturers to determine the best designs. But engineers working with generative design algorithms aren't the first to realize this. The Spanish architect Antoni Gaudi, working at the beginning of the 20th century, arrived at generative design's conclusions working with physical models. The unpredictable curves of his buildings seem like an extravagant luxury (Fig. 6), but there is a purpose to them. Gaudi designed his buildings based on organic forms because he was seeking for form and easy construction that allows maximum resistance with the minimum of materials. Gaudi didn't draw on nature just because he thought it was beautiful; to him, form needed to serve function. To create the strongest and most efficient designs, Gaudi spent hours in his workshop creating and testing 3D models of his designs. These models let him test and scrap designs. Through this testing process, Gaudi found that organically-inspired designs were the strongest and most efficient [10].

Building information modelling (BIM). Another use of AI in architecture is through building information modelling (BIM). BIM involves creating digital models of buildings that hold all relevant information about the project from start to finish. BIM objects have properties that define more than just their corresponding physical object's geometry [11]. The 3D model is enriched with information. Data represents in BIM the deeper elements of information. The list of data can include component specifications, health and safety, production, cost, quality, environmental factors, etc. The amount of data in a BIM model can be significant. Before a computer program tries to learn from data, it is often helpful for a human or data analysis program to study them. Data Science is a set of methods for gathering insights from data. Data scientists often clean the data, extract out important elements, and feed these to an AI to learn further from. This intervention often helps AIs learn better because the AI can focus on selected subsets of the data, thereby improving the learning process [13]. The integration of BIM, Data Science and AI offers new opportunities for design, also from an environmental point of view. The use of data science in connection with AI can for example provide insights and tools for design optimization, for maintenance optimization and for Life Cycle Assessments (LCAs).

Design optimization. Data science can optimize building design by analysing data on energy usage, building materials and other factors. It can also help simulate and visualize building performance. By leveraging data science, AI-powered BIM tools can provide insights into the optimal building design for energy efficiency, sustainability and cost-effectiveness. AI algorithms can analyse data on weather patterns and building orientation. They can use the data to simulate energy usage and analyse the impact of different design and construction scenarios. They can help identify the most energy-efficient materials based on factors such as cost, durability and environmental impact. One example of such an AI-powered BIM tool is Autodesk's Insight [10]. Energy analysis tools have previously been used almost exclusively by building energy specialists. Now the ability to do energy analysis, early in the design phase, is available to architects that can easily change variables and show clients the cause and effect right away.

Maintenance optimization. Data science can analyse data on building performance, energy usage and equipment health. AI algorithms can use the data to detect issues such as leaks, HVAC malfunctions and equipment failures and predict maintenance needs. By leveraging data science, AI-powered BIM tools can

provide insights into the optimal maintenance schedule and identify areas where preventive maintenance can be performed to reduce costs. Example of an AI-powered BIM tool for usage and maintenance optimisation is the BuildingIQ platform [14].

Life Cycle Assessments. For years, architects, engineers, and contractors have focused their efforts on reducing the amount of energy used to operate buildings. As buildings become more energy efficient, a large percentage of the environmental impacts generated over the lifetime of a building comes from the manufacture, transportation, construction, and demolition of building materials. While many architects and engineers are aware of these embodied environmental impacts, few have the

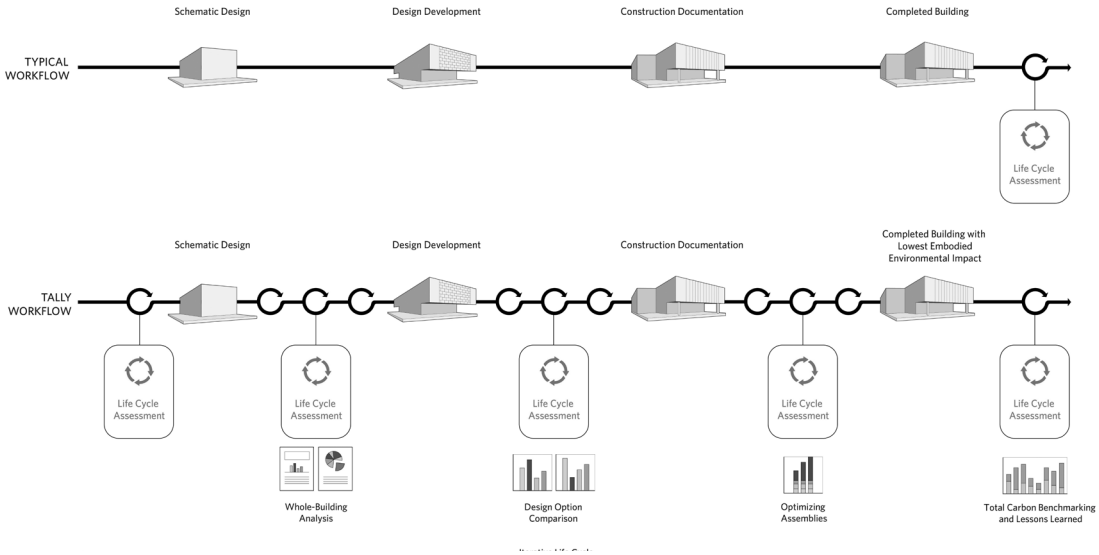

Figure 7: Tally allows users to conduct whole-building LCAs during design and use that data to run comparative analyses of various design options that show their differing environmental impacts (Graphic: Kieran Timberlake).

resources and expertise to be able to examine and compare the overall sustainability of different building and material options. LCAs is the prominent mechanism for measuring a building's energy use and environmental impact, from schematic design and construction through operation and demolition. TallyLCA by Kieran Timberlake is the first LCA integrated tool that can calculate the environmental impacts of building material selections during design directly in an BIM model (Fig. 7). As Tally users design their buildings in Revit, they assign building materials and quantities to create a bill of materials for the full building or constituent parts. This bill of materials automatically updates as the design changes, allowing architects and engineers to see in real-time the impact their design choices have on their buildings' overall sustainability [15]. The potential benefits of AI in BIM are significant and many companies are already starting to explore the use of AI in this area. By leveraging the power of AI algorithms to analyse, interpret, and extract data from BIM models, companies can improve the efficiency and accuracy of their construction projects, reduce costs, and improve the quality of their final product. AI can save time and reduce errors, improve collaboration between different stakeholders in the construction process and the overall quality of construction projects. Nowadays there are several use cases of AI in BIM. However, it is important to be critical and quality-check the provided results [16].

Fig. 7, Tally allows users to conduct whole-building LCAs during design and use that data to run comparative analyses of various design options that show their differing environmental impacts (Graphic: Kieran Timberlake).

Reshaping architecture and design for sustainability

The design process is a creative and problem solving process. The increasing need for environmentally responsible design calls for a workflow where sustainable analysis is implemented as early as possible in this process. The application of AI can be considered at different stages: before, during and after design.

Before design. In this stage, the architect defines concepts and basic ideas. In this phase it's important to learn about the influences and interdependences between different parameters of climate, building design, material properties, usage and comfort conditions [25]. In this respect, AI, thanks to its calculation and analysis capabilities, can play an increasingly important role in cutting down the resources required and improving the final output of the overall research. AI can reduce the amount of time to fast-track it [3].

During design. In this phase different options and materials are compared to optimize the building performance and it's possible to assess the environmental impact of the building. The following are environmental design tasks and operations which can benefit from the use of AI tools [25]:

Climate data and climate analysis
Environmental design criteria
Solar access and control
Daylighting
Thermal and solar-optical properties of constructional elements
Space heating, cooling and lighting energy use and human comfort
Air flow in and around buildings

Other energy sources / uses, other environmental applications Life Cycle Assessments

After design. In the executive phase on the construction site AI can detect potential issues and flaws. During the use of the building it can advise occupants with information on how to use building, assessing effects of different occupancy scenarios, thermostat settings, use of blinds, etc. and allow to adapt the building to daily and seasonal changes. Smart systems will optimize energy usage, monitor occupants' health and enhance security [25]. In general the benefits of AI for architectural design are different: efficiency and time-savings, enhanced design exploration, improved design optimization and performance analysis, cost- effectiveness and sustainability.

Efficiency and time-savings. AI can automate repetitive and time-consuming tasks and save designers a significant amount of time and resources. AI-powered tools and software can assist with tasks such as drafting, documentation, and data analysis, improving productivity and reducing human error. This allows architects to allocate their time and resources more effectively, resulting in faster project delivery [26].

Enhanced design exploration. AI algorithms allow architects and designers to push the boundaries of creativity and explore a multitude of design options. Generative design and AI can produce unique designs that are tailored to the specific requirements of a project. This enhances the creativity of the design process [17].

Improved design optimization and performance analysis. AI empowers architects to optimize their designs by analysing various parameters and performance criteria. This enables architects to make data-driven decisions, resulting in designs that are both aesthetically pleasing and functionally efficient. AI algorithms can simulate the behaviour of structures and materials, allowing architects to test their designs before they are built. This helps to identify potential flaws and areas for improvement, resulting in more accurate and precise designs.

Cost-effectiveness and sustainability. AI algorithms can analyse multiple design options and provide architects with the most efficient and cost-effective solutions. This promotes a more sustainable approach to architecture helping to design buildings that are more sustainable and energy-efficient [18]. In conclusion, tools that use AI are rapidly transforming the architectural design industry, allowing architects to enhance their creativity and efficiency while reducing costs and environmental impact. Increasing availability of the powerful design tool to design professionals significantly limits the damaging effects on the environment. As these technologies continue to evolve, we can expect to see even more benefits in the future, making AI an essential tool for architects worldwide [19].

Humans and AI working together

The radical socio-technical changes we have witnessed since the second half of the 20th century are mainly due to personal computers' advent in people's lives. Like a prosthesis of the mind, the new tools made available by computers have enabled human beings to break down their limits and expand their vision of the future, achieving incredible results until recently. This concept remains valid also for AI, which is simply the next step in the fruitful collaboration where technology is more and more part of a person's mental apparatus and less a mere tool [20]. AI has the potential to change the way that architects approaches the stages of designing buildings and products. AI can provide valuable insights, recommendations, and predictive models that assist architects and designers in making informed decisions. It is crucial for architects and designers to embrace AI as a valuable tool rather than a threat [24]. By leveraging the capabilities of AI, architects can enhance their creativity, efficiency and problem-solving abilities.

Architects will still be critical to the design efforts because they're going to be setting up the problems and requirements deciding what kinds of problems to solve (structural, economical, environmental, etc.), using machines to help them to do a better job. "This is a different way of thinking for designers. It's different to think about designing a system for design instead of several one-off designs. It's different to think about how you can make a whole design system that's going to flex for you" says Lilli Smith, Senior Product Manager AEC Generative Design at Autodesk, practitioner in the field of architecture for more than 20 years [7].

Also the 2023 edition of the Milan Design Week, platform for innovation and creativity in the design industry, reflected a change in the design, influenced by Artificial Intelligence and sustainability. From young designers to fashion brands, many are focused on creating environmentally friendly products and

Figure 8-9: Tilly Talbot AI designer, Stool designed by Studio Snoop in collaboration with Tilly.

using sustainable materials in their creations with some help from AI [21]. In the Design Week the world's first AI designer was even presented. She was presented as a female human-like digital figure on a large screen. Her name is Tilly Talbot (Fig. 8). Tilly Talbot was designed by Studio Snoop founder Amanda Talbot, who was prompted to create the "designer" after her research led her to explore the relationship between human loneliness and AI. Amanda Talbot explained that at Studio Snoop, Tilly Talbot works under the position of "innovation designer" and collaborates with the human members of the team to conceive design objects. Amanda Talbot said that Tilly Talbot has been programmed with Studio Snoop's core values, which include "human-centred design" and prioritising nature. Tilly Talbot collaborated on creating a stool (Fig. 9), she was for example suggesting that timber rather than mycelium might be a better material for it. Positioned underneath each photograph, tablets offered visitors of the Design Week the opportunity to type questions to Tilly Talbot directly and pitch her suggestions on how to improve the designs, which Studio Snoop has now adapted with the feedback it received [22]. In this context it is important to underline that while AI technologies offer powerful tools and capabilities, they cannot replace human creativity, intuition, and critical thinking. AI is still created and used by humans and its efficacy depends on the ability of humans to use it. However, it is also true that AI is opening up new horizons and helping designers to create increasingly complex works. The synergy between human expertise and AI capabilities can lead to innovative design solutions and improved results [23].

Conclusion

AI software for architects offer a huge range of benefits. Architects can now create innovative designs with less effort than ever before [3]. Moreover they have the advantage of being able to simulate their projects in order to test them. The integration of AI in architecture and design opens up new avenues for incorporating sustainable practices into the built environment. AI technologies have the potential to optimize resource usage, reduce waste, and minimize the environmental impact of buildings. AI can provide significant time and cost savings while improving the quality and sustainability of construction projects.

References

N. Leach, Architecture in the Age of Artificial Intelligence: An Introduction to AI for Architects, Bloomsbury Visual Arts, London, 2022.

F.A. Figoli, F. Mattioli, L. Rampino, Artificial intelligence in the design process: The Impact on Creativity and Team Collaboration, FrancoAngeli, Milan, 2022.

Information on https://toolsai.net/best-ai-tools-for-architects/ Information on https://www.dezeen.com/2023/04/26/zaha-hadid-architects-patrik-schumacher- ai-dalle-midjourney/ Information on https://www.archdaily.com/914501/9-augmented-reality-technologies-for- architecture-and-construction

I.A. Joiner, Emerging Library Technologies: It's Not Just for Geeks, Elsevier, Kidlington, 2018.

Information on https://towardsdatascience.com/ai-architecture-and-generative-design- e22320828d46.

I. Caetano, L. Santos, A. Leitão, Computational design in architecture: Defining parametric, generative, and algorithmic design, Frontiers of Architectural Research. 9 (2) (2020) 287-300.

Information on https://www.dezeen.com/2019/04/11/ai-chair-philippe-starck-kartell-autodesk- artificial-intelligence-video/

Information on https://www.engineering.com/story/how-a-century-old-architects-buildings- predicted-generative-design

W. Ma, X. Wang, J. Wang, X. Xiang, J. Sun, Generative Design in Building Information Modelling (BIM): Approaches and Requirements, Sensors. 21(16) (2021).

Information on https://www.thenbs.com/knowledge/the-information-in-bim

Information on https://www.forbes.com/sites/nishatalagala/2022/11/10/ai-and-data- sciencewhat-is-the-difference/

Information on https://www.linkedin.com/pulse/how-ai-data-science-playing-crucial-role- building-modeling-harsh

Information on https://kierantimberlake.com/pages/view/95/tally/parent:4

Information on https://sparkel.io/ai-will-be-the-true-enabler-for-bim-and-construction- productivity/

M. del Campo, N. Leach, Machine Hallucinations: Architecture and Artificial Intelligence, John Wiley & Sons, Hoboken, 2022.

Information on https://www.linkedin.com/pulse/use-generative-design-ai-chad-d

Information on https://www.architecturecourses.org/learn/benefits-ai-architecture-and-design

N. Stoimenova, R. Price, Exploring the Nuances of Designing (with / for) Artificial Intelligence, DesignIssues. 36 (4) (2020) 45–55.

Information on https://www.linkedin.com/pulse/sustainable-design-highlights-from-milan- week-2023-damportugal

Information on https://www.dezeen.com/2023/05/10/studio-snoop-worlds-first-ai-designer/

S. Chaillou, Artificial Intelligence and Architecture: From Research to Practice, Birkhäuser Architecture, Basel, 2022.

M. Del Campo, Neural Architecture: Design and Artificial Intelligence, ORO Editions, San Francisco, 2022.

Information on http://nesa1.uni-siegen.de/wwwextern/idea/keytopic/15.htm

Information on https://research.aimultiple.com/automation-with-generative-ai/