Self-learning Buildings: integrating Artificial Intelligence to create a building that can adapt to future challenges

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Abstract. Adaptability is a crucial quality in nature, and Artificial Intelligence (AI) provides leverage for adaptability in Architecture. In this paper, AI is integrated to create Self-learning buildings that can adapt to future challenges. The aim of this study is to make buildings that collect data from their environment through sensors and adapt themselves according to these data. The approach followed in this study is divided into different phases. Phase 1 starts by making an extensive research on the use of AI in Architecture. The data that was gathered from that research in phase 1 was used as guidelines to design the building in phase 2. The design of the building that is in phase 2 follows a parametric approach with the help of machine learning in the form of computational design tools. An algorithm was designed with Rhino modeling & Grasshopper Scripting to generate forms that not only biomimicks the Coral Growth process but also adapt that form to the selected site of the project. Phase 3 shows the selection process for the generated experimental studies. Multiple analyses were made such as sunlight, radiation, and shadow analysis to select the best performing form in terms of energy use. In phase 4, the form is developed to increase the building’s performance. In phase 5, performance analyses are done to prove that resultant form is a climate or environmentally responsive form which have high levels of adaptability. The analysis showed that the radiation exposure of this building is between 200 and 300 kWh/m². The shadow analysis shows the building form provides a shadow length of 8 hours. The analyses proves that the building’s form reduces its energy use thus makes it adaptable. In the last phase, an AI engine system is used to predict the future expansion of the building. Integrating technology in the architecture of future buildings provides adaptable buildings and helps save some of the energy used by buildings and thus build a sustainable planet.

1. Introduction

The self-learning term may be applied to any machine that mimics actions related to a human mind, such as learning and problem-solving, which refers to the ideal characteristic of artificial intelligence: its ability to rationalize and take actions that have the best chance of achieving a specific goal [¹]. As technology advances, AI is continuously evolving to benefit many different industries [²].
Transcendence, for example, is one of many other sci-fi movies that focused on this topic. The story of this movie specifically predicted that such a computer would create a technological singularity; after an accident that happened to the research team leader, his team studies the possibility of uploading his consciousness into the quantum computer away from his dying body. The system is connected using a complex approach based on logarithms, architecture, psychology, and quantum computing [3]. In this study, we explore the potential of integrating Artificial Intelligence within architecture to create self-learning buildings that can adapt to future challenges and enhance the performance of buildings.

If we look at how architecture was influenced throughout history, we will see that historical event happens every few decades, like a natural disaster, a war, or pandemic, which influences architects to address a new design challenge [4]. The building that we are looking to make provides innovative solutions for any challenge that can face the building by taking advantage of the latest machine learning technologies; it uses a system that merges the use of sensors and bio-digital materials, which harmonize together to deal with any challenges [5]. For example, one of the challenges that we faced in the pandemic era was social distancing; one of the ways we deal with this is through placing smart skin on the building's interior walls which do not pick up any germs, which keeps the spaces sanitized at all times [6].

The self-learning aspect of this building refers to the ability of this building to adapt and learn from all sorts of aspects of its environment [7]. For example, if we put this building in a certain place, the intelligent system would be able to study collect information about the culture of that place and adapt itself to that culture [8]. Another example of what the building can learn is the environmental conditions of its site. So, the building would be able to collect and store data about the environmental conditions and the energy use of the building, and based on that, it decides what necessary action is needed to reduce the energy use of the building, such as opening up and closing down a kinetic facade to reduce sun radiation [9].

2. Methodology
The approach followed in this study is divided into 3 phases. The first phase is extensive research on the use of AI in architecture which explores the use of AI to enhance building performance and the use of AI in the design process. The information gathered from the research is then used as guidelines to design the building in phase 2. The second phase shows our usage of AI tools in the design process. In this phase computational design tools and strategies are used where an algorithm was designed in Grasshopper scripting to generate different experimental studies which are then used in phase 3. The cocoon plugin was used in designing this script to be able to generate curvy shapes that look like they are melting into each other. In the third phase, the most efficient environmentally responsive form for this building is selected out of these experimental studies. The selection process is done by making a sun radiation & shadow analysis for the best six experimental studies, then selecting the best performing form. In the fourth phase, the selected form is developed for better energy reduction. The development process starts by contouring the curvaceous that was selected in the previous stage, then applying adaptive facade to the building. In the fifth, an analysis is done to test the performance of the final form of the building to prove its adaptability. In the sixth and last phase, another AI engine is used to predict the future expansion of this project on a larger portion of the site.

2.1. Phase 1: The use of AI in Architecture.

2.1.1. The use of AI to enhance building performance. When it comes to buildings, new automation systems used to control security, comfort, and energy efficiency are moving towards intelligently controlled solutions [10]. AI allows buildings to become places driven by real-time data and feedback, communicating with itself like a living organism [11]. It creates a world where the building, smartphones, cars, and public places communicate with each other to improve living conditions, limit
waste, increase safety, and limit the traffic that would allow the building AI to predict any challenges that might come up [12].

AI also opens the doors to create smart homes, living spaces that are complex living data-driven organisms [13]. As architects, the challenge is how to use AI to fit into the design language of the home to better improve the lives of the residents [14]. With AI, we would be able to tailor the building performance according to the people needs and have it learn, adapt and respond from the data that it receives from the user [15]. AI in buildings not only take complete care of resident’s comfort and safety but also helps in energy and financial savings [16]. AI-based energy management platforms can track usage patterns to create ideal conditions for tenants which conserves both energy and money [17]. The Nest thermostat (Figure 1) is an example of a system that can adapt and keep the building at a safe and optimal temperature, it can alert users if the temperature increases to reach a dangerous range. AI devices have also the ability to analyse data from sensors to monitor leaks or malfunctions. This makes it easier than ever to track the building’s performance and efficiency [18]. In addition to that, building managers can ensure to maximize operational efficiency, utilize assets reliably, and improve the comfort level of occupants [20].

2.1.2. The use of AI in the design process. As architects, we start our projects by spending many hours on research to understand the design philosophy of that project and similar past projects. However, this process takes much time, and this is where AI comes in [21]. AI can collect and combine limitless amounts of data with little time, make decisions, and give recommendations that ease the architect's research process [22]. The architect would be able to test many ideas and conceptual designs simultaneously without needing the slow process of pen and paper which will result in understanding a better design philosophy in a faster strategy. It is a world where AI has become a design strategy used to leverage the design process. However, it is not convenient to automate the entire design process and solely depend on the AI as there are always possibilities for errors. The real advantage of using AI comes from a collaboration between the human intelligence and the Artificial Intelligence [23].

A major field where AI and Architecture works together harmoniously is Parametric Computational Design, where AI tools have become effective in architecture. Parametric Design allows us to create a parameter-based system that generates forms and structures with such complexity that it would not have been possible for these forms to be imagined or sketched by pen and paper without these tools [24]. AI Software like Grasshopper Scripting gives the architect the ability to use geometric component-based programming with complex algorithms to generate design variations that follow a specific design vocabulary and offer many options [25]. It is almost like an architect's own programming language. These tools can be made even stronger when paired with the Virtual Reality (VR) and Augmented Reality (AR) devices where you would be able to use devices just like the Magic Leap to observe your design as if it is built in front of you and make adjustments from a different perspective [26]. When it comes to buildings, new automation systems used to control security, comfort and energy efficiency are moving towards intelligently controlled solutions [27]. AI allow buildings to become places driven by real-time data and feedback, communicating with itself like a living organism. It creates a world where the building, smartphones, cars, and public places communicate with each other to improve living conditions, limit waste, increase safety, and limit traffic. That would allow the building AI to predict any challenges that might come up [28].

Figure 1: The Nest thermostat AI device which keeps the building at optimal temperature [19]
2.2. Phase 2: Form generation process.

2.2.1. **Concept Development**. The main theme of this project was adaptation, so its concept is biomimicking a process in nature for adaptation. The process that was biomimicked is the Coral Growth and the growth of the Cellular Structures (Figure 2). The goal was to biomimic the process of growth of these organisms that causes them to evolve into an adaptive form. These organisms grow in a way that produces voids in the structure of different sizes. These structures also melt into each other forming bridges between the different cells. In architecture, such voids could help create different-sized patios that allow sunlight to go through the building and reach internal spaces. The formed bridges would act as a connection that can connect the functions on different levels [30].

2.2.2. **Grasshopper script design**. To generate architectural forms that biomimetics the Coral growth as a design strategy, intelligent computational design technology and component-based programming such as Grasshopper (Figure 3) was used to design an algorithm that created a system that can generate complex forms based on logic. These computational design tools and principles were used to leverage in designing a Grasshopper definition that can generate forms that biomimicks that natural process. The Cocoon plugin was used in design the script because it helps in generating curvaceous forms that connect in a way as if they are melting into each other. As shown in Figure 3, the main component on the top left is called Cocoon, it is the core of the script. The Cocoon generates the form based in the input connected to it that are in bottom which are called Charges. These charges are resembling three input parameters. The first parameter is the site surrounding blocks (Figure 4). This way, it is guaranteed to generate a form that is specifically tailored for the selected site. The second parameter is the connections lines that include the connection to the surrounding blocks and the entrances to the site and the overall circulation pattern in the site. To generate a final form, the volume of the function was used as the third input. The volume was used as an input parameter instead of the area of each function to generate 3D forms not 2D patterns. At the end, in the top right is the Smooth component which is used to smoothen the connection between the masses.
2.3. Phase 3: Form selection process.

2.3.1. Experimental studies. In the journey to find the most suitable form, several stages of experimental studies were done. Over 60 experimental studies were done going through different stages as shown in figure 5. In stage 1, the site borders were used to generate a grid to be used as input to generate the form; however, the forms that were produced out of this strategy did not have enough area to fit the functions of this project. In stage 2, The Metaballs approach was used, which is having different balls that resembles the functions of the project melt into each other and form bridges in between; however, this approach was also eliminated because the ball-shaped masses were producing a lot of wasted space and the form bridges from this strategy were inconsistent in terms of volume. In stage 3, a different strategy was used which was filleting the corners of the inner shapes of the site borders, including the shapes of the surrounding sites; however, this approach was not responding to the site as it was cutting through a lot of the site surrounding and roads because of its large patios and long bridges. In stage 4, the used strategy was using the site outlines that were extracted from the roads and the connections around the site to create a grid for the site, then use this grid to generate forms; however, the problem was that most of the volume was concentrated in the bridges and connections and that not only wasn’t working with the areas of the function, but it was also structurally unstable. Stage 5 was divided into three parameters, which was the most successful strategy. The first parameter was the surrounding site zones and their connection to our site, which help in generating the first layer of the form. The second parameter was the lines generated based on the different site factors such as the access points, surroundings, point of view, pedestrian circulation, and roads. The third parameter was the volume of each function, which was used instead of the area to generate a 3D form.

2.3.2. Pre-selection Analysis. Using the strategy of stage 5, over 20 experimental studies were generated and the best six generations in terms of the area, structure, proportions of the bridges & patios, and ease of vertical circulation were selected. To narrow down the selection process, a radiation and shadow analyses were done for the six selected forms to select the most energy-efficient form out of the
six experiments as shown in figures 6 and 7. As seen in figure 6, the form that performed best was highlighted with the red box, as the curvature shape providing lower radiation for the internal part of the form with a value of about 467.98 kWh/m². This is because the size of the patios is smaller in that generation toward the side where direct sunlight hits the building. Similarly, the same generation performed the best in terms of the shadow analysis, as its providing then most volume towards the south, which casted the longest shadow range for the longest period out of all the experiments in that part of the building lasting for 6 hours. The performed analysis helped us in selecting the most environmentally responsive form.

**Figure 6:** Radiation analysis from the best 6 experimental studies.

**Figure 7:** Shadow analysis from the best 6 experimental studies.
2.4. Phase 4: Form development process.

2.4.1. Contouring strategy. To further develop the form, the curvature form was contoured to enhance the performance of the form of this building. The contour strategy (Figure 8) had many benefits, it did not just create a more elegant architectural form, but it also had many functional advantages. The first advantage is the variety in the point of view; using the terraces, all the functions would be able to have access to the view of the canal from the north side. The second advantage was solving the structural problems of the curvature form, moving it to a simple beams and columns structure. The third advantage that the contours granted was the ability to create green roofs, which minimized the radiation going through the building, thus reducing building energy use. The fourth advantage was the increase in the length of the shadow range that covers the bottom surfaces due to the extra layers created by the contours, which reduce the heat of the building, thus creating a more environmentally responsive form. The fifth and final advantage was that adding an adaptive façade decreases the radiation going to the interior spaces.

Figure 8: Applying the contour strategy on the generated curvature form.

Figure 9: final renders of the building showing the green roofs, the levels of the building created by the contours & the Adaptive Facade.
2.4.2. Adaptive façade. One of the elements for adaptivity in the Self-learning building is the Adaptive Façade. The shape of this façade is twisting louvers that compliments the form of the building. This adaptive kinetic façade can sense the sun’s radiation through sensors and take action when needed. When the direct sunlight hits the building, the façade louvers (Figure 9) would twist themselves and protect the building from the radiation. On the other hand, when there is no direct sun light hitting the building, the louver would twist itself to open and bring diffuse natural lighting into the building. Through time and with the help of AI technology, the building would be able to save a recorded history and learn from past experiences. So, it would predict the timings in the year with the highest solar radiation and the timings with the lowest solar radiations.

3. Results and analysis

3.1. Phase 5: Building performance analysis.

After the form development was done (Figure 9), an analysis was performed to test the performance of the building (Figure 10 & 11). The analysis was in two parts, the radiation analysis and the shadow analysis. In the radiation analysis, we can see that the difference between this analysis and the form selection analysis is clear; the contours have decreased the internal radiation because it increased the bottom surface area, which created a bigger shading for the button masses. The inner radiation went down below 400 kWh/m², even before adding the adaptive façade. After adding the adaptive façade, the difference can be clearly seen. Most of the building shows in blue, including between 200 and 300 kWh/m², making this building environmentally responsive. As for the shadow analysis, it can be clearly noticed that the orange areas increased because of the contours, and the shadow length increased to last about 8 hours.

**Figure 10: Building Performance Radiation Analysis.**

**Figure 11: Building Performance Shadow Analysis.**
3.2. Phase 6: Adaptive expansion system using AI.
AI has many potentials in design. An AI engine called Deepart.io was used to predict the future expansion of the building on the project’s site and the city of Dubai. This is a global AI engine that has been used by international universities like The MIT & organizations like AA in London. This engine can alter a picture based on a given style which acts as the parameter which controls the output. So, a picture of the site was inserted as input with another picture of one of the experimental studies (Figure 12). The AI was able to study the style of the building and produce an output showing how the entire site would look like when filled with this form. In Architectural terms, this AI engine was able to predict future expansion based on its information as a parameter.

**Figure 12**: AI application in design to predict future expansion.

4. Conclusion
Adaptive designs are the key to creating sustainable architecture, and with AI, we can mimic adaptivity in architecture from nature. The journey of achieving adaptability in this project was done on different phase:

- **Phase 1**: A research on the use of AI in architecture which discuss the use of AI to enhance the building performance and how to take advantage of AI in the design process.
- **Phase 2**: Using computational design tools such as Grasshopper scripting to design a script that can generate different kinds of adaptable forms.
- **Phase 3**: The generation of the experimental studies and selecting the most energy efficient form based on radiation and shadow analyses. The selected form had a radiation of 467.98 kWh/m² and shadow length for up to 6 hours.
- **Phase 4**: The development of the form for a better energy performance. The development was through the Contouring Strategy and the Adaptive Façade.
- **Phase 5**: Performance analyses to prove that the final building is environmentally responsive. The result was a radiation below 400 kWh/m² with the contouring strategy and between 200 and 300 kWh/m² after adding the Adaptive Façade. The shadow length increased to 8 hours.
- **Phase 6**: Using an AI tool called depart.io to predict the future expansion of the building on a larger portion of the site.

In conclusion, this research was exploring the potential of using AI in architecture and with the results that showed how the technology helped in creating an environmentally responsive design, it is very clear that AI technologies are powerful strategies to be considered and implemented within architecture. The implementation of AI technologies within architecture starts from the beginning of the design process all the way to the functionality of the actual building. Dubai, being one of the competitive countries when it comes to technology, have big potential in implementing a project like this. The big limitation in this field is the scarcity of the minds that can develop good AI technology which makes implementation expensive. Finally, design and technology are increasingly becoming more connected to each other, it will open a door for new areas of research and redefine how future architecture will look like.
Key words

Artificial Intelligence (AI); Computational design; Environmentally responsive Design; Architecture; Performance Computing Systems; Adaptability; Machine learning.

Acknowledgement

This research was supported/partially supported by University of Sharjah, College of engineering, Architectural engineering department. We thank our colleagues from Architectural engineering department who provided insight and expertise that greatly assisted the research.

This paper and the research behind it would not have been possible without the exceptional support of Eng. Haydar Basel Kamil Al-Beer, We thank him for his great contribution and assistance with particular technique, methodology, and Dr. Emad Mushtaha and Dr. Moohammed Wasim Yahia,Professors, Architectural Engineering Department, College of Engineering, University of Sharjah, for comments that greatly improved the manuscript.

We would also like to show our gratitude to the “anonymous” reviewers for their so-called insights. We are also immensely grateful to iBIOSDG2021 Conference Scientific Committee. For their comments on an earlier version of the manuscript, although any errors are our own and should not tarnish the reputations of these esteemed persons.

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