Applications and Evaluation of AI Technologies in the Renovation of Old Buildings in Urban Centers

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Abstract. Urban sprawl or expansion is a growing issue globally, and as technology continues to develop, the demand for residential areas continues to rise. Conflicts regarding the availability of resources for architecture also rise in rural areas; therefore, renovating old buildings in urban centers becomes an important concept. Since there are many challenges with renovating these buildings, the recent development of AI technologies will provide solutions to mitigate or reduce these challenges. This paper examines the application of AI technologies in architecture and how they contribute to redeveloping old buildings in urban areas. Technologies such as conditional Generative Adversarial Networks and deep neural networks can assist architects in standardizing floor plans and generating design modules. In addition, these technologies analyze data from existing buildings and, thus, can create the best possible plan for a building. While these technologies focus on simplifying the traditional process of architectural planning in areas such as generating programs and creating partitions, B-SMART reference architecture approaches architecture from the perspective of smart home building, therefore, implementing AI technologies into the lives of the residents. Furthermore, with AI technologies, future homes are created to be energy efficient and sustainable. Therefore, the application of AI will improve the sustainability of homes and overall benefit the environment.

Keywords: Old Buildings; Renovation; Artificial Intelligence; Digitization.

1. Introduction

As technology continues to develop, urban sprawl and especially the urbanization of rural areas are growing immensely across the world. This development and growth eventually causes the demand of houses or residential areas as well as the availability of land to grow proportionately with technological development. Thus, leading to conflicts regarding the obtainable resources regarding architecture. Similarly, the costs associated with building and construction also increase due to the scarce resources. Furthermore, urban centers and large cities often have historical significance. Therefore, renovating or redeveloping older buildings could damage the city's layout and historical elements causing the city to lose its historical and cultural contexts.

Due to these reasons, it becomes extremely difficult for architects to redevelop old buildings, especially in large cities and urban centers. However, with the recent developments regarding AI technology, there have been proposals on how this problem can be mitigated and minimized. This paper provides preliminary discussions regarding the subject.

2. Current State of Old Building Redevelopment

The United Nations estimates that 55% of people live in urban areas as of 2018 [1]. The urban population has grown exponentially from a census detailing data from 1960 to 2016. In 1960, 2 billion people were living in rural areas, which is twice as many as the population in urban areas. However, in 2016, 4.4 billion people lived in an urban environment, whereas only 3.4 billion people lived in rural environments. This data shows that the urban population has grown 340% while the rural population has only increased by 70%. Even though this comparison is from 2016, there is no doubt that the urban population have grown even more in 2023. With such a densely populated environment, the demand for available housing increases.

As mentioned previously, old buildings are difficult and complex to renovate, due to the differentiating styles of many urban areas. These buildings also have to be addressed in a case-by-case manner. Different buildings could have different levels of safety and require different programs. Thus, it is difficult to create a standard for redeveloping old buildings. The redevelopment often requires collaboration from multiple parties, for example, the architects, the construction team and the local government.

Moreover, the surrounding communities of the redeveloped area would also likely be involved. Hence, the architects and construction team would likely have to coordinate with the local community and authorities to avoid unnecessary conflicts. Due to these significant barriers, many high-level architects and construction companies would not want to participate in such redevelopment. However, with the implementation of AI, it can effectively integrate both the modern standards of construction and more traditional life methodology.

3. Current State of AI Technologies

Since the 21st century, computer and informational technologies have evolved, and digital technologies have already been used in the construction industry. In terms of architectural design, using statistical analyses from various digital mediums, such as AI, can enhance modern architectural design capabilities [2]. AI technologies also bring new and innovative features to the current design state.

3.1. 3D Architectural Design

The digitization of architectural data allows various modelling softwares to combine and share data. This enhances the modelling software and makes it more effective for architects and clients. Sharing data or simply gathering large amounts of data can evolve architectural design from being solely about the structures to considering areas such as materials, interior design and decor. Therefore, making the process of designing architecture more user or client-oriented.

3.2. Diversification of Forms

With the application of architectural digital technology, various parameters and algorithms in the design process are becoming more and more abundant and diverse. These parameters and algorithms enable architects to innovative ways of design. Thus, adding new possibilities that were not possible with the traditional way of design.

3.3. Refinements in Architectural Construction

Not only has the digitization of data and architectural design brought benefits to the design aspects of the industry, it also revolutionizes the construction of it. Digitization provides the construction process with accurate and precise information at each stage of it. By optimizing the efficiency at each stage, it can also track the progress of construction with high degrees of accuracy. Therefore, reducing the time required effectively using the available funds. Communication between the architects and the construction party is also clearer with precise information, hence, also improving efficiency.

While these are all significant changes and overall benefits in the field of architectural design, there are also areas where AI technology and digitization are lacking. For example, the data may be incomplete or imprecise, and through the digitization process, the data might contradict each other. Therefore, digitization poses a problem regarding how to judge the rationality and effectiveness of data. Another issue with designs based on data analysis is that they could be difficult to execute with the current construction technologies. The appearance of AI would likely mitigate these issues. Since AI is essentially a decision-making system based on data it can use its data to provide auxiliary support for the architects. Furthermore, AI could be a self-learning process, providing architects with a logical design plan. AI can learn and achieve complex goals, making architectural design a process that can be controlled and optimized.

4. Case Studies

Despite the implications and novelty of AI technology, there have already been developments specifically made for the field of architecture where AI contributes to the design and planning process of an architectural project. Though none of these technologies has produced real-life applications, there is significant progress in terms of development and speculated uses.

4.1. The Application of cGANs and Conceptual Design Generation

Conditional Generative Adversarial Networks (cGANs) continue to gain popularity. In terms of the architectural field, there are already models using cGANs to generate conceptual designs [3]. For example, the Pix2Pix. The model uses a simple input-output system and essentially, creates floor plans based on the data collected from 800+ apartment floor plans. This technology also follows the geographic location or site of the construction, and thus, determines a set of conceptual floor plans that best suits the site. Similarly, the program and furnishings of the building can also be generated through this algorithm. Pix2Pix produces individual images of each floor, if these floor plates are assembled together then AI could generate the plan of an entire building. Therefore, making architectural planning much more efficient.

Regarding the redevelopment of old buildings in urban centers, these areas often have issues with small sites and high costs due to the lack of space within cities, leading to difficulty of transporting construction materials or tools. Using cGANs technology can easily mitigate or reduce these issues as it generates plans based on the geographical location and caters to each building or site, there would be less time spent on the planning phase of construction. The reduced time would also significantly benefit the redevelopment of old areas or buildings. As mentioned above, old buildings in urban areas are often congested, making it difficult for many construction equipments to travel in and out of the city. Thus, reducing time in the areas where possible, such as planning, can reduce the costs of using construction equipment and the transportation of them and materials. Additionally, shortening the duration of each architectural project can also reduce costs in terms of labour. These two benefits that come with lowering project duration also link to maximizing the profit. Essentially, with less time spent working on the architectural project through cGANs, architects can increase their efficiency and earnings.

Old buildings often have small rooms and each resident has little space. Therefore, multifunctional rooms are crucial to these residents' quality of life or general lifestyle. It would likely be easier to combine various functions cohesively through cGANs' planning technology based on the required programs and residence size. Overall, making the experience better for both the architect and the client, in short, it is mutually beneficial. Similarly, cGAN technology can also generate logical programs and circulation plans for a building [3]. Since the model also generates multiple plans, it allows for more flexibility in the design process without taking much time. Thus, making the cGAN technology an enhancement to architectural design.

4.2. The Application of Deep Neural Network

One application in development of AI in architecture is the deep neural network (DNN), which collects data from various designs, converts them into modular blocks, and assesses them based on their function and performance [4]. Through this assessment, the program then recombines the modules into new buildings. During this development, 15 homes were referenced and used as a database for the DNN. Each homes' layout, program, livability and "sleepability" scores were inputted in the DNN. The AI then analyzes the programs and layouts associated with high liveability and "sleepability," allowing it to generate design blocks that optimize those factors. Its effectiveness is proven as it accurately predicts the liveability scores for existing homes. For example, the AI predicted the liveability score to be 51.2 while the accurate score was 51. There are a few errors with the DNN's algorithm.

From the assessment criterias of this study, it clearly focuses on the human experience with architecture. In other words, it focuses more on comfort rather than the aesthetics of the building. Factors relating to human affairs in homes are sometimes overlooked when planning or designing a residence. However, through the use of this DNN, it helps the architect plan these factors. The AI could also potentially suggest new ideas or concepts that are not commonly seen, thus creating an optimized plan every time. Rather than experimenting with different designs and concluding through trial and error, which is often used when designing elements that caters to a human's experience, AI assists the architect in avoiding blunders. Therefore, similar to the previous case with cGANs, the designing process is much more efficient.

Being able to analyze homes and recombine various programs for optimization is key for the redevelopment of older buildings or residences. Many people living in these buildings are elderly or senior citizens. As the world's population ages exceedingly rapidly, they suggested that by 2050, 15.9% of the world's population would be above 65 years old [5]. By 2100, it would reach 22.6%. Thus, the population living in old buildings within urban areas would continue to follow the trend and age as well. The use of AI in the redevelopment of these residences can help determine the most suitable living environment for these citizens.

Since this DNN centers on the concept of liveability and "sleepability", it can be directly linked to the quality of life of the elderly. Many elderly people struggle with the quality of their sleep and experience issues such as insomnia or sleep apnea. Hence, having a high "sleepability" is key in redeveloping their residences. Improving "sleepability" is likely a difficult task for the architect without the analysis from AI programs. However, it would be much easier to improve on the factor with its assistance. Similarly, as this technology develops further, it could assess other factors regarding human lifestyle such as the effects of natural light and colours on one's emotions and how these factors can be improved to yield a better quality of life. While these factors can be applied to all buildings, it is especially vital to older buildings housing seniors as they are more vulnerable to both the physical and psychological effects of architecture.

4.3. B-SMART and TMU's DCC building

B-SMART is the reference architecture regarding the area of automatic smart buildings [6]. Reference architecture often means creating a sense of standardization in architecture design. Standardization would decrease the costs associated with building and construction, making architectural design more readily available to the general public. In terms of older buildings, standardization allows concepts in modern architecture to be integrated into it, thus redeveloping and revitalising them into modern society.

The B-SMART reference architecture is largely based on a knowledge repository organization as the smart building automatic manager requires it [6]. It essentially gathers the key information or data from an architectural project and curates it into a database. From this database, the reference architecture focuses on fit-gap analysis. Furthermore, B-SMART has already been applied to in an ongoing project regarding the Daphne Cockwell Complex (DCC) building of the Toronto Metropolitan University (TMU). The existing structure of the DCC is compared to the database of B-SMART. Therefore, the AI can identify any missing conceptual elements to improve the building. Similarly, since B-SMART centers around smart home design, the AI also compares the DCC building with its automatic control capabilities. By comparing the two subjects, constructing a plan into making the DCC building an automatic smart building would be more effective and efficient. With this AI technology, architects can minimize errors in their planning and preparation phase, creating the best possible plan [7].

The DCC building is located in downtown Toronto, which is densely populated and has many old buildings that have not been redeveloped. In short, older buildings in downtown Toronto are a quintessential example of the subject of this paper. Therefore, the technology used here also applies to the surrounding area. It is widely known that redevelopment in these areas is difficult due to various factors, for example, the lack of modern technology such as centralized heating and cooling systems.

Even though these factors may seem unremarkable in the architectural industry, these factors are extremely important in determining one's living standards. With the comparison between a new cutting edge AI and older buildings often lacking modern technology, B-SMART can significantly improve the living conditions of older buildings. In fact, to create an automatic smart home system, living standards in these buildings after improvement would likely exceed the standards in typical middle-class homes. Improvements could potentially include security cameras to promote a safer living environment and controlling light and temperature settings to conserve energy.

As mentioned previously, many residents in these areas are elderly, meaning that smart home features are more beneficial to them than a young adult or a middle-aged person. For example, a senior with Alzheimer's could tend to leave their home and struggle to return afterwards. Smart home features such as cameras could track the senior's movement in and out of the home and therefore, alert family members or caregivers if they leave at an illogical time, for example, late at night. Therefore, it decreases the chances of the senior going missing. There have also been studies regarding senior quality of life when affected by smart home technology. From a study in 2022 that assesses senior quality of life based on the personal wellbeing index (PWI), the total quality of life improved from 80.79 to 84.81 after the installation of smart home technology [8]. Specifically, the PWI grew from 85.33 to 88.67 in the personal safety section. Thus, it is clear that the implementation of smart home technology benefits seniors' wellbeing and quality of life. With B-SMART's assistance, it would be easier to implement these features, hence, aiding the redevelopment of older buildings.

4.4. Sustainable and Energy-Efficient Smart Homes

One key goal for smart homes is the concept of sustainable and energy-efficient buildings [6]. Furthermore, smart homes also attempt to mitigate the effects of climate change and reduce carbon emissions; these factors also contribute to the world's sustainability. AI is often a major contributor to the building of smart homes, and since AI is largely based on data collection and analysis, big data (BD) can analyze data surrounding the use of energy efficient buildings and formulate plans to benefit the structure [9]. For example, upon the analysis of relevant data, the AI can propose techniques or algorithms to optimize system performance within the energy efficient building (EFB). The AI gathers information to minimize errors and enhance the structure by using local and global weather data, historical data, building codes, and databases developed by commercial companies related to energy research such as DOE. In contrast, if humans were to attempt the same method, it could potentially be difficult as it is easy to make errors and combine different pieces of technology or data together to create the best possible plan. Additionally, AI analysis takes up a significantly shorter time than human analysis.

Even though BD and AI in the area of EFBs had not been applied to real-life buildings, this technology has proposed applications. For example, using BD and smart windows, the AI can adjust the opacity of glass based on the weather conditions and daylight hours [9]. A similar concept can also be applied to shutters and blinds. The AI could also use light sensors to check light intensity and determine whether lights need to be turned on in an indoor environment. Adjusting the lights or electricity usage also contributes to energy efficiency and sustainability as AI would only choose to turn on the lights when necessary. Furthermore, adjusting the blinds and window settings would also likely allow more natural light into the building, which is an indirect way to conserve energy.

In regards to older buildings in urban areas, these technologies could help lessen the impacts caused by the geographical locations of these buildings. Since these buildings are located in urban areas, they would be crowded together with little space between them. Therefore, these residential areas often lack privacy. Using AI to adjust the windows' settings can help determine when the owner needs more privacy and when it would be best to have fully transparent windows and allow the greatest amount of natural light. Thus, limiting the energy consumption to be more sustainable.

Sustainability and the overconsumption of energy is also a prevalent problem in modern society, with issues such as rising temperatures and greenhouse gas emissions affecting countless countries. These issues are especially common in congested urban areas. For example, 75% of global primary

energy is consumed by urban areas, as they require an interrupted and constant supply of energy [10]. However, while the demand for energy is high, growing at a rate of 7% each year in developing countries, the supply of energy sources remain unchanged each year. Overall, causing a global energy crisis. In terms of architecture, the process of building it and humans residing in it are major contributors to energy consumption. Hence, if AI can contribute to both the planning and building stages of architecture, for example, through the technologies mentioned previously in this paper such as cGANs and DNN, then it could significantly decrease energy consumption within the construction sector. Similarly, through smart home technology such as adjusting light intensity, AI technology can reduce energy consumption on an individual level. Regarding older buildings, these buildings often do not have modern technology installed to conserve energy and promote sustainability. Due to their location and high costs, many older buildings within urban areas have not been renovated, thus, explaining the lack of technology. With the aid of AI and its analysis on new technology and collection of BD, it could make renovating and updating utilities such as electric systems much more affordable and efficient, contributing to decreasing global energy consumption.

Additionally, with the concept of smart cities, the idea of improving buildings or areas to be more energy efficient through AI can be applied on a larger scale. Ideas regarding this development have already been speculated, and proposals on the subject. For example, creating a data center that visualizes and simulates energy usage within a city to gather information and uses AI to analyze it to optimize energy utilization [11]. In short, the technology used to create smart homes and smart cities is inherently the same. However, speculated smart city development demonstrates AI-induced smart living potential.

5. Conclusion

Architecture does not necessarily mean buildings or houses. However, it is a part of one's lifestyle, society, and is the bond between humans. Architectural design is inseparable from urban transportation, energy supply, health care, social security, education and culture for a city. With the rising technologies today, AI demonstrates a promising future for architectural design in digitization. Through AI technology, the designs can be more imaginative, refined and personalized; furthermore, architecture can also be more culturally diverse and improve to be efficient and economical.

Nevertheless, the state of AI technology today has yet to reach the level of practical and reliable applications in real life, much of the research is speculated or suggested methods. The lack of real-life applications is primarily due to AI's current algorithmic capabilities, standardization of the architecture data, and the structure of databases not performing at a high-level. Therefore, these factors are also areas of improvement for the future. With the accumulation and continuous development of AI along with architectural or building technologies, the future of architectural design would likely use calculated and rational algorithms to combine interdisciplinary knowledge, utilize AI analysis to build models, and propose efficient solutions for project management. Cities would age, houses would deteriorate, however, through AI technology's aid, it can contribute too many architects' work and revitalize old buildings.

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