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ASSESSMENT OF THE CURRENT STATE OF AI-AIDED DESIGN IN ARCHITECTURE

CASE STUDY: DESIGN OF A RESIDENTIAL BUILDING IN RIYADH CITY

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ABSTRACT

The high potential of current AI tools makes this technology a promising tool to resolve many issues in different fields. In the AEC field, AI-aided design tools have shown to be beneficial during design process from its very beginning stages. However, it usually requires human intervention and result-iteration as normal progress for a recently-developed technology. It is seen that the most productive strategy is the relationship between AI and human intelligence in which is referenced as ‘augmented intelligence’. In this research, the capability of AI-powered tools has been tested regarding architectural design. A residential building in Riyadh City was chosen for a redesign case study. The AI proposal design has been divided into two phases presented in the floor plan layouts and the building façade design. Depending on the type of task to be resolved. A comparison among a bunch of related AI tools has been implemented based on specific criteria to select the best fit for each of the phases. GenAI, presented in ArchiteChures tool, produced the layouts. In a later stage, layouts have been slightly modified manually to rectify inaccuracies. The final result has been reviewed and evaluated in reference to the requirements parameters in Riyadh City and to the original proposal. For façade design, a diffusion-based model has been utilized presented in MidJourney tool. The final design was accomplished through an iterative process via hybrid text and image-to-image technology. The results have been reviewed and evaluated regarding the level of accuracy and creativity.

The experiment reveals the current potential of two different types of AI technologies. It is confirmed by the evaluation that AI is still not able to dominate in the field at the current time. However, as seen in ArchiteChures and MidJourney, this capability varies based on the AI model and the task performed. While it was somehow challenging to reach the optimal spatial layouts, the result of the façade design showcases the high capability of this kind of AI models.

KEYWORDS: AI-aided design, spatial layouts, Façade design, Iterative design process, Augmented Intelligence.

تقييم الوضع الحالي للتصميم بمساعدة الذكاء الاصطناعي في الهندسة المعمارية
دراسة حالة: تصميم مبنى سكني في مدينة الرياض

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الملخص

في مجال العمارة والهندسة والإنشاء، أثبتت أدوات التصميم بمساعدة الذكاء الاصطناعي أنها مفيدة أثناء عملية التصميم منذ مراحلها الأولى. لكن عادةً ما يتطلب الأمر تدخلًا بشريًا كتقدم طبيعي لتقنية تم تطويرها مؤخرًا والتي يشار إليها باسم "الذكاء المعزز". في هذا البحث، تم اختبار قدرة الأدوات التي تعمل بالذكاء الاصطناعي فيما يتعلق بالتصميم المعماري. تم اختيار مبنى سكني في مدينة الرياض لدراسة حالة إعادة التصميم. تم تقسيم التصميم المدعوم بالذكاء الاصطناعي إلى مرحلتين تشملان

المخططات وواجهة المبنى. اعتمادًا على نوع المهمة المطلوب حلها، تم إجراء مقارنة بين أدوات الذكاء الاصطناعي ذات الصلة بناءً على معايير محددة لاختيار الأنسب لكل مرحلة. أنتجت أداة GenAI المخططات، ثم تم تعديلها يدويًا بشكل طفيف لتصحيح الأخطاء. وقد تم تقييم النتيجة بالرجوع إلى معايير المتطلبات في مدينة الرياض والتصميم المقترح الأصلي. بالنسبة لتصميم الواجهة، تم استخدام نموذج diffusion-based والذي يعتمد على ترجمة النصوص والصور إلى نتائج بصرية (صور). وقد تم تقييم النتيجة من حيث مستوى الدقة والإبداع. تكشف التجربة عن الإمكانات الحالية لنوعين مختلفين من تقنيات الذكاء الاصطناعي.
يؤكد التقييم أن الذكاء الاصطناعي لا يزال غير قادر على الهيمنة على المجال في الوقت الحالي. ومع ذلك، كما هو واضح في ArchiteChtures وMidJourney، تختلف هذه الإمكانية بناءً على نموذج الذكاء الاصطناعي والمهمة المنجزة. على الرغم من أنه كان من الصعب الوصول إلى المخططات المثالية، فإن نتيجة تصميم الواجهة تنبئ عن القدرة العالية لهذا النوع من نماذج الذكاء الاصطناعي.
الكلمات المفتاحية: التصميم المدعم بالذكاء الاصطناعي، المخططات المكانية، تصميم الواجهات، عملية التصميم التكراري، الذكاء المعزز.

1. Introduction

Architectural design is an iterative process that requires several improvements during its different phases in order to achieve the required quality of results given budget and time constraints. Therefore, introducing automated design techniques that have the potential to generate diverse design options reduces the time and cost of the design [3]. The latest revolution in AI technology has cast a shadow over architecture, engineering, and construction (AEC) sector, adopting unprecedented technological advancements and innovations. Currently, AI is typically used for tasks involving learning and problem solving [1]. In his book, the author refers to John Kelleher's definition of AI; 'artificial intelligence (AI) is a scientific discipline that focuses on creating computational systems that are capable of carrying out tasks and activities that are typically associated with human intelligence'. While the term "augmented intelligence" describes a form of hybrid intelligence that pairs artificial and human intelligence in order to maximize both machine and human capabilities while decreasing their drawbacks [7]. It is obvious that due to the groundbreaking advancements brought by the AI-aided technology, the human-machine interaction amended the process of design relatively, in which AI augments the creativity and innovation of design methods and strategies [7]. Digital technologies have transformed the way architecture is practiced, managed, and guided, allowing a reciprocal relationship between designer and design tools. This type of human-machine interface and interaction technology includes various techniques including 2D and 3D presentation, parametric design, coding, scripting …etc. [7].

Therefore, architecture sounds to be one of the pertinent practices that will be dominated by AI in the near future. The research explores the potential of this fast-emerging technology in generating an architectural design project using specialized and non-specialized AI-aided design tools. The case study implemented a mix of AI tools: GenAI and diffusion-based. The findings will determine the current ability of AI to generate functional and aesthetic design outputs.

2. AI Applications in Architecture

Artificial intelligence is an effective optimisation technique that is used to analyse a wide range of situations. It is made up of layers and neurons that mimic the architecture of the human brain. Backward learning methods can be used to train artificial neural networks with learning and memory capabilities [10]. Despite having a history spanning more than 50 years, artificial intelligence is still in its experimental development phase, where its potential is being explored [7].

However, it is important to emphasize that, in addition to saving time and generating large number of iterative options, AI permits until recently unprecedented advancements in all fields- and in the field of architecture and design-. AI algorithms are utilized to examine data and identify trends and patterns that can direct the design process [2]. These processes now include parametric design, performance evaluation, optimisation of structural solutions, and prefabrication of both individual building components and entire structures (also using 3D printing technology) [14]. Mainly, the role of AI as being is broken down into four stages: recognition, evaluation, reconstruction, and generation. Starting with sampling or searching, the design process comes out with a range of outputs instead of a single design. This tendency in the AI era is shifting the role of architect from maker to controller, in which the emphasis lies on the precision of the search rather than creativity, that becomes the AI's role. However, the architect's sensibility of aesthetics cannot be neglected in any term in the design process [1]. The term Computer Aided Design has been used for a while. In the current time, it could also be called AI Augmented Design. AI will definitely influence design thinking. It will be a part of new design tools that humans will develop, and future design skills will be developed as an extension of the human brain and hands [1, 16]. The term Augmented Intelligence has been first defined by Douglas Engelbart in 1962. According to him, increasing a person's intelligence entails giving them the ability to understand concepts more quickly and effectively, come up with better answers, and even solve problems that previously were insurmountable. Since the turn of the century, hundreds of Al algorithms have been devised. For now, these algorithms are solving particular kinds of issues or performing particular kinds of jobs from the conventional search engine to the state-of-the-art deep neural network when applied to the right task [16].

In the process of architectural design, spatial layout planning is usually a repetitive and time-consuming process. It has been recently considered to be assisted with AI tools in order to promote the design process. This advancement approaches while maintaining the role of architects as curators is one contribution to the current hybrid human and AI interaction [6]. The process of spatial layout planning typically consists of three key concepts: geometry, which establishes the dimensions and forms, topology, which explains the connections between them, and semantics which defines extra features like the function of a room in addition to other elements of floor plans such as text, icons, dimensions, windows, furniture, and the relationships between these elements, making information recovery and automatic analysis a complex task. Hence, automation of spatial layout planning can reduce the complexity of the process [13]. Automated architectural plans can be applied mainly through three methods: (1) bottom-up, it begins with defining the members, the space function, and the space requirements' parameters. The initial order is generated according to the parameters, and it developed gradually after result evaluation. (2) Top-down, it defines boundaries, characteristics of the spaces, and functions, an initial layout is produced by the objective function and then adjusted gradually. The spaces are distributed inside the primary boundary in this method. (3) Referential, it uses the dataset from the precedents, and a model is customized and trained as a neural network or data cluster. The model formulates the problem specified by the designer, then it processes the geometric data and generates the result [9]. In artificial intelligence, the automatic generation of architectural floor plans is a developing field. It has the potential to significantly increase designer's productivity and facilitate quick alternative exploration. The introduction of AI in the process of floor plan design initiates advanced approaches of design. These approaches include data-driven design based on customized data manipulation, comprehensive layout models based on using numerous databases, and generative floor plans that learn from precedent examples [6].

In the context of architectural design, generative scripts tools have provided designers with disruptive concepts and opens up creative possibilities for design ideas. These tools also make it simpler to manipulate data and develop creative solutions for challenging issues, improving the opportunities for creativity of designers beyond conventional approaches [12, 14]. AI research focuses on image, text, and voice-based applications and has resulted in ground-breaking advancements in text, image, and voice algorithms [5]. A created digital image in the context of architectural design is just the first step in the production process. It is essential saying that creating an architectural concept speed up considerably when the creative process is automated [3]. Simple text descriptions can be used by recent diffusion-based AI art platforms to generate visually striking images. This makes them effective tools for concept design in any field where tasks involving visual design creativity are needed. This also applies to the initial phases of architectural design, which involve several ideation, sketching, and modelling stages [8]. Zhang et al. [15] experiment in their study how designers would incorporate generative image AI with design sketches in the early stage of design. Findings show that AI is a handy tool to get inspired with design ideas. Nonetheless, AI is not capable of offering design decisions. Generative networks have several scenarios including unsupervised learning, multi-domain image synthesis, and conditional image synthesis. In their research, Ali et al. [4], explore the potential of creating façade design by AI using iFacade tool. They depend in their research on utilizing the conditional image generator. The aim was to generate new building façade by mixing two existing building façades in the neighborhood. They concluded that current tool follows the modular architectural style because the generated façades have characteristics of the reference, so the outputs for different buildings with special characteristics in façade may be limited. Another research explores using MidJourney as a design-assisting tool during concept generation, mimicking architect's works, and developing façade designs. MidJourney functions in the previously mentioned exercises as an inspiration tool in the initial stage of design [3]. Generating visual outputs is not only limited to producing outputs from databases alone; they can be generated by inverting the network in a process of reversing the information flow. DeepDream is one of the tools that begin with a category and then proceed to generate an image, as opposed to identifying an image and then classifying it. For instance, starting with the category "cat" and generating an image that resembles a cat, whereas a standard neural network can recognize an image of a cat and classify it as a "cat" [1]. This feedback loop improves the capacity of generative adversarial networks (GANs) to produce pertinent images when the discriminator is identifying the images. Then, the Generator is trained to produce images that look like images from the same dataset. The Discriminator gives the Generator some input regarding the calibre of the images it produces. By means of this feedback loop, a GAN gradually enhances its capacity to generate pertinent synthetic images by accounting for phenomena identified within observed data [14]. This technology not only speeds up the conceptualisation stage but also promotes creative design solutions that conventional methods might not be able to produce at once. Generative design algorithms generate design options that are optimised for particular criteria [11].

3. Research Problem

AI technology has grown exponentially in the last years, resulting in enormous developments in all disciplines. Yet, it is not very clear how AI is affecting the field of architecture and design. The emergence of AI-aided tools augments the creation of unique and distinctive designs. While it is worth mentioning that the generated fancied designs may not be practically applicable. Thus, this research explores in AI design tools to find out the present capability of AI in producing proper architectural designs.

4. Research Questions

This research raises several questions in relation to the AI-aided design and AI-powered tools as following:

1) Is there a tool that generates proper and functional architectural solutions?
2) What are the suggested tools that may ease the process of design by AI?
3) To which extent the design is accurate, so it does not need to be edited by the designer?
4) Is AI completely capable of generating functional and aesthetic designs?

5. Research Hypothesis

The research hypothesizes that incorporating advanced technologies in the process of architectural design is enhancing the quality of the design outputs as well as assisting in decreasing the effort and time needed to complete a project. It also assumes, based on the recent huge advancements, that the potential of AI is becoming much wider which makes the process of design more creative, productive, and convenient.

6. Methodology

The research adopts the analytical descriptive approach in the theoretical part discovering AI applications in architectural design, and AI-aided tools. First, an overview of the AI-powered design have been discovered, this includes exploring in the application of automated spatial layout planning and generative scripts models. Second phase was designated to develop two comparisons according to certain criteria among GenAI design tools and diffusions-based tools. Two tools have been selected for the later design proposal.

The experimental approach has been followed in the practical part to discover the ability of AI tools in producing reliable design outputs. The case study that takes place in Riyadh City has already an existing proposal of a residential building designed by a professional architectural firm. It will be used as a control state for the evaluation in a later phase in addition to the gathered requirements of the residential buildings according to the Ministry of Municipal and Rural Affairs. The AI spatial layouts have been generated by the selected AI-aided tool ArchitChtures, applying all needed requirements. As a final step, manual modifications have been made to the plans to rectify some errors. Subsequently, the quality of the generated outputs has been assessed comparing them to the original proposed plans in terms of functionality and accuracy of technical details. In regard of façade, this phase includes generating façade design of the building using Midjourney tool. The process uses hybrid image-to-image and text-to-image translations iteratively until the required design has been achieved. The final phase is set for façade evaluation in terms of aesthetics, creativity, and accuracy of design.

6.1. AI design tools

Artificial intelligence is becoming a new creative partner for architects across the industry. It is already about to enter a digital revolution that will unlock automation and hitherto unimaginable possibilities, integrating machine and human potentials. With new programs being announced every day, the list of AI tools for architects is growing quickly. In connection to the case study, the criteria have been developed for the specialized GenAI-based design tools that are targeted to be involved in the case. In order to select the most relevant tool for this case study, several features were determined to be included in the tool. Firstly, the tool has to be specifically designed for residential planning. It also has to provide proper data input options. Moreover, parking design options to be included in the design. The following table compares some of the most-known AI tools in residential design.

Table. 1: A comparison among GenAI tools specialized in residential design planning.

AI Tool	ArchiteChtures	Maket AI	ARK Lite	Conix AI
Description	Generative tool for residential planning and analyzes site conditions and budget.	Generative tool enables architects to generate architectural plans instantly.	Generative tool for residential schematic design.	Generative tool for residential plans starting from zoning phase to detailed furnished plans.
Features	-Easy user interface. -Free trial. -Wide range of input data options. -Enables 3D view. -Plans distribution by percentage or numeric values. -Underground parking options. -Importing from file or generating from scratch. -Offers site analysis. -Generates project data schedules. -Offers cost estimation. - Exporting to BIM, CAD, and XLS.	-Easy user interface. -Generates 2D plans, 3D renders, and visualization. -Technical and stylized plans. -Zoning program. Modifications by AI restyle or manual. -Importing from file or generating from scratch. -Exporting to DXF and JPG. -3D renders can be imported as a reference.	-Easy user interface. -Free use. -Generates proposals for zones. -Generates schematic design. -Plans distribution by percentage or numeric values. -Evaluates efficiency of results. -Generates project data schedules. -Enables manual modifications. -Enables 3D view. -Exporting to RVT and PDF.	-Easy user interface. -Free trial for a project. -Offers house zoning preferences according to the location. -Generates proposals for zoning program (bubble diagrams). -Generates proposals for architectural plans, furniture layouts, MEP layouts, and elevations. -Enables manual modifications. -Exporting to DWG and PDF.
Limitations	-Limited plot dimensions. -Lacks some manipulation options. -Manual editing is not iterative. -Advanced options are premium.	-Limited plot dimensions. -Lacks some manipulation options. -Advanced options are premium.	-Limited plot dimensions. -Lacks some manipulation options.	-Only villas design. -Limited plot dimensions. -Lacks some manipulation options. -High price.

According to the comparison, the tools have different capabilities which requires a test for each tool. The case study was the tested to determine the best application that fit the requirements of the case. Unfortunately, none of the tools were capable of generating large floor plans. For that, the case study project has been modified to a smaller scale. The most appropriate tool was

ArchiteCtures due to the wide range of data input options and the option of adding underground parking. The analysis offered by the tool could not be processed since the version used was educational.

Table. 2 displays some of AI visualizing tools that are diffusion-based. These tools mainly generate images from text, which called text-to-image generation models. It is worthy of note that these tools are not specialized tools, they are more artistic. Yet, the high potential of creativity in these tools make them broadly used in varied design fields. In the following table, some of the most popular image generation tools are selected based on specific features including textual prompts and image permutation, and realistic outputs. The comparison aims to discover the capabilities of each of these tools that could engage in creating a realistic façade.

Table. 2: A comparison among diffusion-based design tools.

AI Tool	MidJourney	Stable Diffusion	DALL-E	Imagen/ Vertex AI
Description	Diffusion-based generative artificial intelligence programs that mainly generate images from natural language descriptions, called prompts.			
Features	-Text-to-image generation. -Image-to-image generation. -Artistic style. -Different image iterations. -Inpainting which fills in the missing areas of an image. -Outpainting which fills out or extends beyond the original image. -Object Recognition. -High Image Resolution. -Free trial.	-Text-to-image generation. -Image-to-image generation. -Creation of graphics, artwork, and logos. -Image editing and retouching. -Inpainting which fills in the missing areas of an image. -Outpainting which allows users to fill out or extends beyond the original image. -Video creation. -Free access for basic plan.	-Text-to-image generation. -Different image iterations. -Image editing and retouching. -Inpainting which fills in the missing areas of an image. -Outpainting which allows users to fill out or extends beyond the original image. -High Image Resolution.	-Text-to-image generation. -Different image iterations. -Image editing and retouching. -Inpainting which fills in the missing areas of an image. -High Image Resolution. -Get answers to a question about an image with Visual Question Answering (VQA). -Free trial.

As shown in the table above, the tools are almost equally capable with similar features. However, and after primal attempts done by the researcher, MidJourney has been selected as the most familiar tool to be utilized in this case study to generate the façade using text and image translation.

6.2. Case study

The objective of this experiment is to investigate the current AI-aided design and its current capabilities. The case study is taking place in Riyadh City, in Hittin District. It is a residential site located on a 38x30 m2 interior lot on a 36-meter street and surrounded by 3 neighbours. It is worth to mention that the selection of the plot and the building floor plan type was challenging because of the dimension and manipulation constraints of the AI tools. However, the selected spatial layout has already been planned previously by practicing team and it will be referred to as the original layout in this paper. It is divided to form a twin building consisting of 3 floors with a connection in between them containing the elevator. Each floor contains 4 units, in addition to 2 penthouses, and underground parking **Fig. 1**. In this case study a redesign of the existing proposal will be generated by AI technology in order to evaluate the capability of AI tools in providing well-solved spatial layouts and façade designs. As mentioned above, ArchiteChtures was selected to generate the new floor plans through a top-down method where inputs are set generally and developed gradually after generating the initial layout. On the other hand, MidJourney was chosen to generate the façade design. It employs a diffusion process based on a huge dataset, in which it reconstructs the output images from the source images.

Fig. 1: Residential Floor plans for a twin building produced by a professional architectural firm. A) Basement. B) Ground floor plan. C) First floor plan. D) Penthouse.

6.3. Requirements of residential buildings in KSA

According to the Ministry of Municipal and Rural Affairs and Housing (MOMRAH) [17], residential buildings are the buildings that consist of more than 2 floors, with a total height not exceeding 23 meters above the ground and contain number of residential units not less than 3 units. Following are the main spatial and technical requirements issued by the Municipality.

6.3.1. Spatial distribution requirements

a) Percentage of construction on the ground floor not exceeding 60% of the area of the plot of land.
b) Percentage of construction on the first floor and typical floors not exceeding 70% of the plot area.
c) Construction percentage for the penthouse does not exceed 50% of the area of the floor below it, not including the vertical movement elements (stairs and elevators). The construction percentage for the vertical movement elements in the penthouse is additional, with a maximum

of 10%. Anything more than that is counted as a part of the construction percentage of the penthouse.

d) The front setback is 1/5 of the street width, and not less than (3 m). The setback from neighbours is not less than (3 m) for buildings more than 5 floors, and (2 m) for buildings of 5 floors or less.

e) Providing (1.5) car parking spaces within the property boundaries for each residential unit.

6.3.2. Technical requirements

Technical Requirements Compliance -in general- requires the Saudi Building Code, and all Ministry of Municipal and Rural Affairs laws regarding residential buildings, with the implementation of all equipment, and materials in accordance with Saudi specifications. These also include applying architectural, mechanical, and electrical requirements. The next part mentions the architectural requirements that will be applied to the case study.

6.3.2.1. Architectural requirements

In this case study, the proposed design will prioritize the main relevant architectural requirements regardless of mechanical and electrical requirements which do not have relation to this context. These requirements comprehend universal design that is targeted to be accessible by all persons, areas and heights, shafts, entrances, basements and penthouses, in addition to natural lighting and ventilation.

A. Universal design

a) Universal access requirements must be applied to residential buildings consisting of 4 residential units or more, commercial residential buildings, and administrative residential buildings.

b) The requirements of people with disabilities must be met with the aim of facilitating their movement and creating the appropriate conditions and dimensions for their use, whether in parking lots, slopes, or various spaces.

B. Rooms' areas

a) The minimum required elements of the residential unit (a living room or hall + bedroom + bathroom + kitchen).

b) The surface area of any of the building's rooms or facilities shall not be less than the minimum limits for the following dimensions and areas shown in **Table. 3.**

Table. 3: Interior spaces' minimum dimensions in residential buildings according to MOMRAH.

Space	Minimum area (m2)	Minimum width (m)
Living room, Dinig room, Salon	11.2	2.8
Bedroom	6.5	2.1
Kitchen	5	1.8
Bathroom	2.8	1.4
WC	2	1.2
Maid room	6.5	2.1
Corridor	-	0.9

C. Heights

a) The maximum height of the residential ground floor above the level of the middle of the sidewalk in front of the building entrance is 1.20 m, and its minimum height is not less than 30 cm from the level of the middle of the sidewalk in front of the building.
b) The building height calculation does not include the height of the penthouse or public service facilities (elevator rooms - stairwells - water tanks), which have a maximum height of 6 meters.

D. Shafts

a) The area of shafts designated for lighting and ventilation of the building's rooms and facilities must not be less than the minimum limits of the following dimensions shown in **Table. 4**.

Table. 4: Shafts minimum dimensions in residential buildings according to MOMRAH.

Shaft height and type	Minimum length (m)	Minimum width (m)
Two-storey-high shaft, contains windows that open from one or two non-opposite sides.	1.8 m	1.2 m
Two-storey-high shaft, contains windows that open from two opposite sides or from all sides.	1.8 m	1.8 m

E. Entrances

a) The minimum width of the residential entrance is 0.80 m.
b) It is allowed to create a stairway or ramp for the entrances to residential or commercial buildings within the regular setbacks, in a way that does not obstruct the design of surface parking lots and is in line with the sidewalks.

F. Basement

a) It is allowed to build a basement on the entire surface of the land.
b) The basement is allowed to be used for parking, ancillary electrical and mechanical services, and service or entertainment accessories.
c) An entrance and exit must be provided for the parking floor below the surface of the ground. It is permissible to provide one ramp with a width of no less than 4 m in parking lots whose capacity does not exceed 25 spaces. However, if the number of parking spaces exceeds 25 parking spaces, it is necessary to provide a separate entrance and exit with a width of no less than either of them is less than 3.50 m.

G. Penthouse

a) It is permitted to construct an upper extension used as a separate residential unit or units or connected to a unit on the floor below it, or as supporting services for the roof of the building, and a car parking must be provided for it if it is used as a separate residential unit.
b) The area of the penthouse on the roof floor must not exceed 50% of the area of the floor below it, not including the vertical movement elements (stairs and elevators). The building percentage for the vertical movement elements in the upper annex is additional, with a maximum of 10%, if exceeding, it shall be counted among the construction percentage of the penthouse.

c) It is not permitted to make openings or windows directly towards the neighbours. The spaces of the penthouse may be illuminated and ventilated through openings overlooking the roof's setback, or skylights.

H. Ventilation and natural light

a) Natural lighting and ventilation must be provided for all building rooms and facilities for residential units of various types, so that each residential room and building facility has one or more openings for ventilation and natural lighting whose total area is not less than (8%) of the floor area of the rooms designated for housing.
b) Kitchens in residential units are allowed to be part of the living hall space, provided that the required ventilation for the living hall and kitchen is provided and fumes are expelled in an effective manner.

6.3.3. AI-generated floor plan layouts

At the outset, the outline of the plot and the building have been imported to ArchiteChtures AI tool as a reference. The top-down method is basically followed in the tool, where outline of the building is determined first, then inside spaces are adjusted gradually. The spaces are distributed inside the primary boundary in this method. The first attempts to generate the floor plans were totally unapplicable. While the two buildings in the original proposal are connected through an elevator foyer, it was hard to draw the same outline exactly in ArchiteChtures. **Fig. 2** displays an example of a typical floor plan generated by the tool in the very beginning attempts. As seen, areas are distributed by the tool to have natural ventilation and light, ignoring the proportion of areas and functionality of the rooms, besides that it was not possible to determine exactly the location of corridors and cores.

Fig. 2: AI-generated typical floor plan by ArchiteChtures in the first attempt.

To solve the problem, the building has been divided into completely two separate units using two generating lines. The building's plot dimensions are determined to be 26*11.5 m2. The target layout was 10 apartments in total. 4 apartments on the ground floor, 4 on the first floor, and 2 penthouses in the roof. Referring to the original proposal, each apartment has to contain a living room, a kitchen, a master bedroom with bathroom, 2 bedrooms, 1 room (either a guest room or an office), and 2 bathrooms. Penthouses have the same distribution with no guest room or office.

All data are determined in the input panel according to the requirements of residential buildings mentioned above and the target spatial layout. Minimum dimensions have been also determined in the input panel. Options in the tools do not provide customized rooms options; it offers the option of a studio, or an apartment with 1 to 4 bedrooms. For that, the option of 4-bedroom apartment was opted. Graphically, the green circle indicates that the minimum dimensions are met. While yellow colour represents that dimensions are near to meeting the minimum, and red colour represents that dimensions are far from the minimum required. **Fig. 3** shows the generated layout of the ground floor. It demonstrates that all rooms are close-fitting the minimum dimensions.

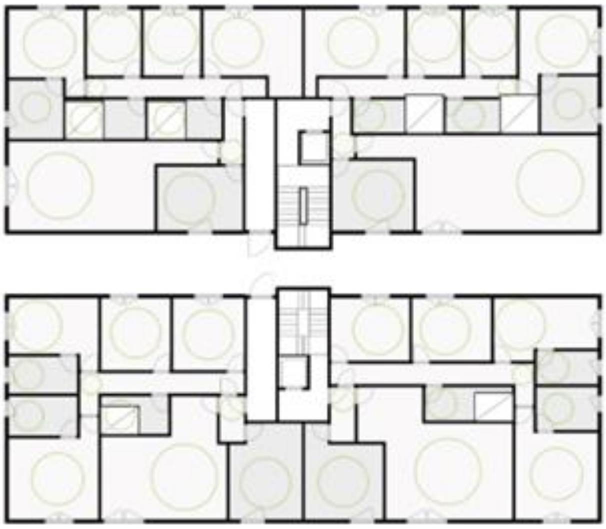

Fig. 3: AI-generated plan by ArchiteChtures.

Referring to MOMRAH and in respect of setbacks, 1/5 of the street is required for the front setback. This is equal to a 6-meter setback on the 36-meter street. For side and rear setbacks, 2 m from each side is required since the building is less than 5 floors. The imported outline has already considered the required area of setbacks, because of low flexibility of the manual manipulation in the tool

For the car parking, it is required 1.5 parking for each unit, which means 15 car parking in total. On the ground level, 6 parking spaces are considered in front of the entrance, but there was no option in the input panel for generating car parking on ground level. In the underground parking, the tool works more freely as it allows to draw generating boundaries and lanes. On the other hand, there is no option to determine the number of parking spaces required, so many attempts have been made to reach the most efficient layout. Eventually, the best layout has contained 21 parking spaces exceeding the minimum required. Additionally, the storage area in the basement is not clearly defined. The layout does not contain doors and openings, and the sidewalk is missing in the layout. Circulation is also neglected; the stairs and the elevator have no clear access.

In detail, each floor contains two separate layouts, in which each two apartments are similar in distribution. The following figures show the space detailing for one apartment of each layout on the underground parking, the penthouse, in addition to the ground and first floors, referring to them as typical floor. It should be noted that the area of the two front ground apartments is smaller than the upper apartments, affected by the underground parking ramp. Yet, this relation between the underground level and ground level has not been considered by the tool at all.

According to spatial distribution requirements, construction areas were taken into consideration before creating the layout. Since the land area is 1,140 m2, the footprint must be a maximum of 60%. The building area is approximately 690 m2, equivalent to about 60% as per requirements. The upper floor exactly matches the ground floor, so the area is 60%, 10% less than the maximum allowed. The penthouse must equal a maximum of 50% of the floor below it, with 10% for the circulation elements, while in the actual plan it equals 415 m^2, 60% of the area, and the core equals roughly 45 m^2, 7% of the area.

Figure 4: AI-generated typical (ground and first) floor units by ArchiteChtures.

Fig. 5: AI-generated penthouse units plan by ArchiteChtures.

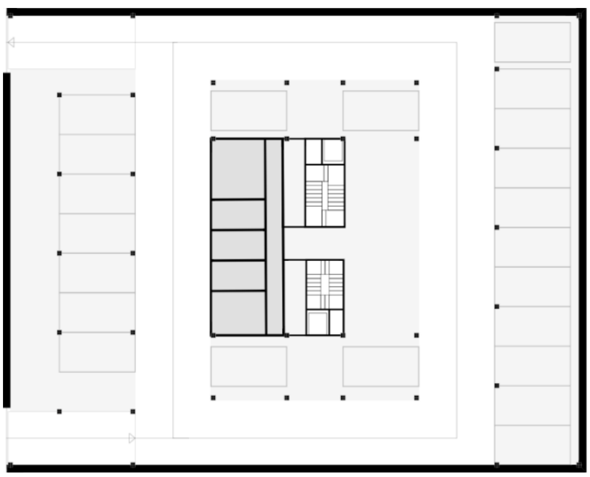

Fig. 6: AI-generated basement by ArchiteChtures.

In the context of architectural requirements, the tool does not specify options for universal design particularly, such as car parking for disabled. On the other hand, elevators are provided for vertical circulation as one of necessary elements for accessibility, and most of the interior spaces meet the minimum required dimensions for movement. However, applying the universal design is not considered as a target in the tool. Regarding room areas, all spaces satisfy the minimum requirements conveniently. About heights, the input panel does not include an option in regard of the height of ground floor above the ground level, which makes an error in the relation between the ground floor and the basement as the area of the ramp has not been deducted from the ground floor. The penthouse height is set in the input panel to be 2.8 m. About shafts, the dimensions are determined to be 1.5x1.5 m for the first building, and 2x2 m for the second building as a maximum. As per the requirements, the minimum width of the residential entrance is 0.80 m, and it was met in the layout. Ramps and entrance steps do not have an option to be inserted. In addition, there is an error in the layout not considering an opening between the entrance and the staircase.

For the basement, its boundaries are determined to be as the boundaries in the original proposal. It is divided into car parking and storage. As it was planned to include the largest possible number of parking spaces, two ramps for entrance and exit with 3.5 m width have been made to meet the requirements. The distribution is well-defined, except for the storage area that has no clear entrance and openings. As shown in **Fig. 5**, the distribution of the penthouse has fatal errors. The corridor is taking the largest area of the apartment while other rooms are with the minimum dimensions required. Regarding the requirements of the penthouse, the area exceeds limit by 10% because only 10 m was allowed for the front setback in the options of penthouse in the input panel. In order to overcome the constraint of not having opening towards neighbours, the built area is set back from its two sides by 1 m.

Natural lighting and ventilation are provided for all building rooms and facilities. The area of opening in each space has been roughly estimated to satisfy the requirement of 8% of the room area. Since the kitchen is separated from the living room, it has its own ventilation opening.

Yet, some missing elements can be noted in the plans, including windows in some of the bathrooms. There are two shafts for two adjacent bathrooms, each overlooking its own shaft. In addition, it appears that shafts were added above the plan, as the bathroom area was calculated including the shaft area, and the shaft wall appears to be parallel to the bathroom wall at a very close and illogical distance. This was the weakest part of the plan. Moreover, the shafts do not appear in the penthouse which means that there is no relation among the generated floor plans. The irregular distribution of the living room in the second building is also a waste of space. **Table. 5** summarizes the percentage of achieving forementioned requirements as applied in the AI solution.

Table. 5: Evaluation of the results achieved according to the requirements of MOMRAH.

Type	Requirement	Percentage achieved
Spatial Distribution	60% construction on the ground floor.	100%
	70% construction on the first floor and typical floors.	100%
	50% construction percentage for the penthouse, and 10% construction percentage for the vertical movement elements.	60%
	The front setback is 1/5 of the street width. The setback from neighbors is not less than (2 m).	100%
	(1.5) car parking spaces within the property boundaries for each residential unit.	100%
Architectural	Universal design	10%
	Areas	60%
	Shafts	50%
	Heights	70%
	Entrances	80%
	Basement	70%
	Penthouses	50%
	Natural ventilation and light	80%

6.3.4. Manual modification on the AI-generated designs

ArchitChtures offers manual editing at the last stage, in which the layouts cannot be iterated again. In order to improve the plans, modifications have been made to the layouts, taking in consideration not to make major changes to the original layouts generated by AI. They will be referred to in this paper as hybrid layouts. **Fig. 8** illustrates the ground floor plan after the manual editing. Spatial distribution was maintained as the original generated plan, except some changes occurred to the following:

a) An opening door to the core has been added in the entrance hall.
b) The walls of the hall have been removed and the hall space made wider.
c) One of the two shafts of the bathrooms has been removed, and the other relocated to be between the two bathrooms, and the walls are adjusted.
d) Missing windows in the bathrooms were added and windows' locations have been adjusted too.
e) The living room wall has been shifted to allow for more space in the bedrooms.
f) The fourth bedroom has been renamed as (other), in reference to the original proposal which includes either a guest room or an office; this option was not available in the auto mode.

In **Fig. 7**, the ground floor plan shows the dimensions after the manual modifications. While adjusting the plans, it was essential to preserve the optimal dimensions of the rooms.

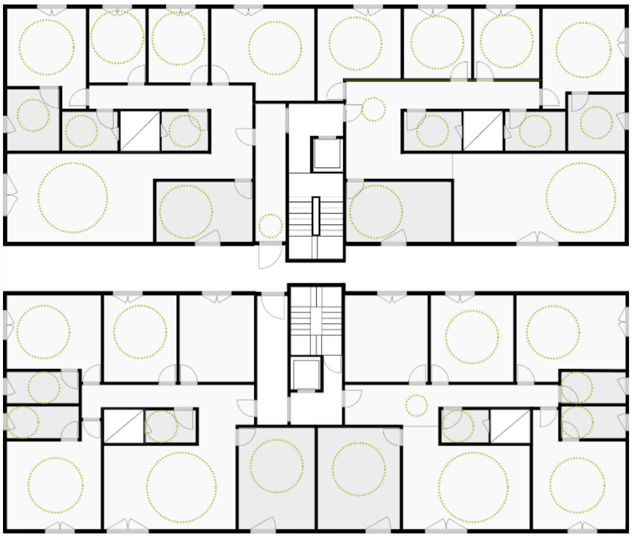

Fig. 7: Hybrid AI-manual plan by ArchiteChtures.

Fig. 8 and **9** show one unit of each building after the manual editing. These modifications rectified some errors, except some errors that could not be edited because of the original structure of the AI plan.

Fig. 8: Hybrid AI-manual layout of the typical floors.

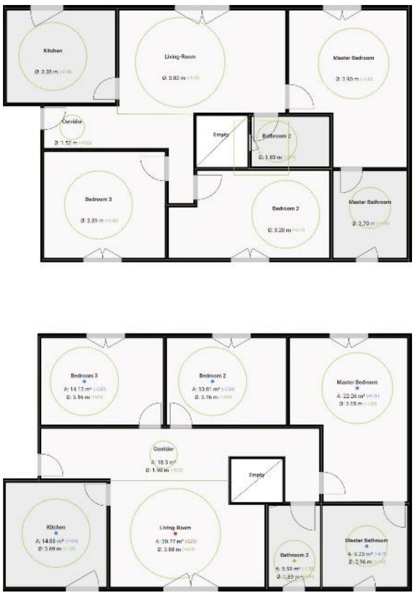

Fig. 9: Hybrid AI-manual layout of the penthouses.

6.3.5. Comparison and Evaluation of GenAI tool ArchiteChtures

This section will compare the result obtained by AI and hybrid AI-manual solutions to original proposal. Values from 1 to 10 refer to the level of achievement of the criterion. 1 for the least achievement result, and 10 for the highest achievement result. **Table. 6** displays the total sum of the evaluated points. It is shown that original plans are still superior. Meanwhile integration of AI with manual adjustment assists in developing the quality of the AI-generated plans. Overall, ArchitChtures has shown good performance regarding input options and visual outputs. It is still in demand of development to meet more advanced requirements of residential buildings. Despite being a promising architectural tool, some limitations compromise depending on it totally in its current status. Some solutions were totally unapplicable because of the unreasonable dimensions. Other limitations include the lack of flexibility in creating non-typical units, some architectural elements are not considered in the floor plans, such as emergency exits, and location of shafts, the generated plans are not connected to one another properly, etc. Although some of faults can be rectified manually, it still shows the lack of recognizing architectural elements, proportions, and dimensioning. The tool also seems to give advantage for some requirements over others causing imbalance in the distribution, as shown in the first attempt where lighting and ventilation were the most important requirement in which the plan is distributed based on it.

Table. 6: Comparison of assessment of the achievement of the three used methods.

Criterion	Original layout	AI-generated layout	Hybrid layout
Professional result	10	6	8
Technical details	10	5	7
Editing process	10	2	5
Time	5	8	7
Total	35	21	27

6.4.1. Façade design

The next step of the proposal was generating façade design using MidJourney. To get to the best result, hybrid text and image prompts have been used in an iterative manner. At first, the 3D view of the twin building has been extracted from ArchiteChtures. It has been inserted to MidJourney under the prompt (/describe). The tool generates four textual descriptions for the 3D view. After editing the descriptions properly, they were mixed and merged into one prompt. Midjourney textual prompts have been also mixed with prompts generated from Chat GPT that assist in structuring the prompt appropriately. One of prompts used in the first attempts was described as follows: "A flat perspective view of a twin residential building with three stories and penthouse, high detail, high quality. architectural rendering in grey accents, contemporary style, green landscape, a three-meter corridor in between the buildings, two ramps on the sides to the underground parking". The final textual prompt was added iteratively with random images of residential modern twin buildings were collected to get inspired from **Fig.10.** They were blended respectively with the textual prompt to generate option for the façade design.

Fig. 10: Images of residential twin buildings façades used as inspirations in MidJourney prompts. A) 3D visualization published by https://pin.it/3hw32WjiU. B) 3D visualization by Dezcon https://www.dezcon.com.au. C) 3D visulation by Arch.Noureddin https://www.behance.net/gallery/143499559/Attached-Villas.

The process of replicating the prompt with input images led to different image results every time. For that, seed number, a unique number generated with each output, was used in the prompt to keep the same identity of the design. Even though results were still showing variety in results, the designs belonged to the same spirit. Obviously, MidJourney made an interesting blend of inspiration images creating completely new designs. However, some elements were missing in the visualization, like penthouse, parking ramp, wrong locations of openings, in addition to a fence added to all the designs. The tool was weighing some descriptive phrases more heavily than others, this is subject to the way the tool is digesting the inputs. For that, a weighting should be added after the phrases that need more focus. Yet, this was not very useful in the case of this façade design, as the images were taking the heavier weight presumptively in the tool. **Fig. 11** shows the final results obtained from MidJourney. The tool reconstructed the input image mixed with textual prompt to generate a façade with similar architectural elements. Though, the design lacks reality and accuracy. Penthouse floor, entrance path, and parking ramps are not considered.

Fig. 11: Residential twin buildings façades generated by MidJourney for the proposal of the twin building.

6.4.2. Evaluation of AI GAN tool MidJourney

It is noteworthy that MidJourney is not a specialized architectural tool. Nevertheless, the outputs were satisfying and inspiring in terms of design and visualization. The iteration of text descriptions blended with images helped ending up at acceptable results with high quality. The tool depends on a huge dataset that reconstruct images randomly, which means hundreds of images generated from the same prompt input iteratively. However, some outputs seemed to be very fancy and unapplicable in real life. This makes the tool cannot be relied upon especially in regard to proportions and fine details since it is an artistic not an architectural tool. On the other hand, the inputs have to be developed gradually to achieve better results. The precision of the outputs is also related to the accuracy of the text prompts given as input. Moreover, the structure of the textual prompt has a high impact on the quality of the output. Organizing the phrases in the prompt with the most important details to the least important promotes the performance expected from the tool. Regardless of proportions and missing parts, the results of façade designs seem to be realistic and applicable. At its current level, the tool can be utilized as a primary design tool in conceptual design.

Conclusions

The paper addresses some aspects of promising aided-design tools assisted by AI technology. The experiment highlighted generating floor plans and façade design using artificial intelligence. In respect of generation of floor plans, the tool used is the GenAI ArchiteChtures residential planning tool. As for the building façade design, the tool used is the diffusion-based AI tool MidJourney. In both tools, the process of generating results was somehow flexible, allowing for replication and control. Nonetheless, the process is still in demand of human supervision and editing. At the end of the experiment, the researchers concluded that:

1) The results revealed the potential scope of current AI design tools. Regarding the floor plan generator, the output needed manual adjustments that could not be achieved by the AI mode. In addition, the available options were limited to a certain level of control manipulation restricting the scope of manipulation.
2) Although reasonable results were achieved, the proposal was chosen after investigating the potential of the tool. Previous attempts have failed due to lack of options to generate unique types of plans. These include duplex apartments, rum plan layouts, large plots, etc.
3) Other limitations are attributed to the tool's lack of recognizing the relationships between different elements to each other and linking the storeys to each other correctly.
4) Regarding the façade design tool, the results were striking and unconventional in terms of design, visualization, and fast outputs. However, the tool is not accurate enough to rely on as an architectural design tool without modifying the results. However, the outputs can be infinite due to unlimited iterations; it assists the designer to get inspired by the wide range of results.
5) Overall, visual results showcased superiority over the results obtained for the floor plan layouts due to the fast and creative outputs generated. While in the spatial layout, the result was of a moderate quality.
6) Despite current limitations that make AI technologies need human supervision, the power of AI will certainly initiate, with rapid advancement, a great coming era in architectural design.

Recommendations

This research targets software developers and practicing architects and designers. It is definite that AI will be a dominating tool in the future of AEC field. Hence, and subject to the conclusion, AI tools have already entered the field of architecture with high capabilities. However, AI design tools are still in demand of wide and precise development to match the requirements of architectural design process. Future research should be dedicated to the strategies and methods of architectural design as a complex interconnected process.

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