Generative Adversarial Networks (GANs), and Architecture: Investigating Quality in Architectural Plan Generation

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Artificial intelligence (AI) finds extensive applications in architecture, alongside various other domains of daily life. Recent years have witnessed a surge in visual processing, analysis, and production, primarily propelled by deep learning algorithms. Among these algorithms, Generative Adversarial Networks (GANs) stand out as exemplary tools for image generation. Within architecture, GANs are utilized across various domains including facade design, interior layout, and generation of perspectives and architectural plans. Notably, GANs have emerged as prominent tools in architectural plan generation. However, unlike other image synthesis tasks, architectural plan generation places greater emphasis on plan quality over image fidelity. Consequently, evaluating the quality of plans generated through AI poses a novel and contemporary challenge. While some studies touch upon quality issues in GAN-generated outputs, a comprehensive exploration of quality-related concerns remains lacking. The study analyses the plans generated by GAN and assesses the capacity of GAN in ensuring architectural quality. To this purpose, a study is undertaken to analyze existing architectural plan generation studies utilizing GANs and to interpret the notion of architectural quality. The studies analyzed that the experiments with GANs are preliminary and there is a lack of studies on the production of higher quality plans using GANs. However, these studies seem to be due to the limitations of GAN itself. This study concludes by underlining the limited capacity of the GANs to enhance the quality of architectural plans, and provides comments and reviews on this matter.

Keywords: GAN, Architectural Plan Generation, Quality in Architectural Plan, Artificial Intelligence.

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Çekişmeli Üretken Ağlar (ÇÜA) ve Mimarlık: Mimari Plan Üretiminde Nitelik Araştırılması

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Yapay zekâ, günümüzde yaşamımızın her alanına nüfuz eden bir araştırma alanına dönüşmüştür. Bilgisayarların karmaşık sorunları insanlar gibi ele alıp çözmelerini hedefleyen yapay zekâ; sayısız alanda daha önce çözülmemiş zorluklara araçlar ve yöntemler getirmektedir. Yapay zekâ uygulamaları mimarlık alanında da aktif olarak kullanılmaktadır. Mimarlıktaki akıl yürütme sürecine benzer bir sistemin yapay zekâ teknolojileri ile oluşturulabileceği birçok araştırmacı tarafından öngörülmektedir. Bu anlamda birçok araştırmacı Yapay zekâyı, mimarlık alanında ortaya çıkan "Sıradaki Büyük Şey" olarak görmektedir.

Günümüzde özellikle derin öğrenme algoritmaları yardımıyla mimarlıkta görsel işleme, analiz ve üretimlerine dair uygulamalar artmıştır. Derin öğrenmenin bir türü olan, ÇÜA (Çekişmeli Üretken Ağ) görsel üretimi üzerine en iyi örnekler veren algoritmalardan biridir. Görsel tabanlı bir algoritma olan ÇÜA'nın başta görsel üretimi olmak üzere, görüntüden görüntüye, metinden görüntüye, fotoğraflardan çizime gibi birçok uygulaması bulunmaktadır. Mimarlık alanında ise, cephe, iç mekân, perspektif ve plan üretimleri gibi birçok alana yayılan bir kullanımı vardır. Mimarlık alanında ÇÜA yardımıyla yapılan çalışmalar incelendiğinde özellikle mimari plan üretiminin öne çıktığı görülmektedir. Mimari plan üretimi, özellikle erken aşamalarında alternatif plan çözümlerinin şekillenmesi ve ortaya çıkması gibi tekrarlanan işlemlerin olduğu bir süreç olması sebebiyle yapay zekânın araştırma alanına girmektedir. Bu sebeple mimari plan şeması üretimi, tasarımı ve mekân kurgusu üzerine yapılan çalışmalar, yeni bir araştırma alanı olarak karsımıza çıkmaktadır. Mimari plan üretimi konusunda yapay zekâ yardımıyla son yıllarda öncü çalışmalar yapılsa da, mimari plan üretiminin diğer görsel üretiminden farkı görselin kalitesinden daha önemli olan üretilen görselin niteliğidir. Bu nedenle de üretilen plan şemalarının niteliğinin değerlendirilmesi yeni ve güncel bir problemdir.

Çalışma kapsamında ÇÜA algoritmasının mimari plana dair nitelik problemlerine ne ölçüde cevap verebileceğinin araştırılması hedeflenmiştir. Bu kapsamda öncelikle ÇÜA algoritması kullanılarak üretilen mimari plan üretim çalışmaları incelenmiştir. Kullanılan ÇÜA algoritmalar ve özellikleri kısaca değerlendirilmiştir. Mimari nitelik kavramı araştırılmıştır. Mimarı niteliğe dair incelenen literatürde niteliğin katmanlı bir kavram olduğu, nesnel ve öznel farklı gereksinimlerin göz önüne alınması gerektiği görülmüştür. Çalışma sonucunda niteliğin ve plan üretiminin çok katmanlı bir süreç ile elde edildiği sonucuna varılmıştır. Bu sebeple de çalışmada plan üretiminin doğası ile ÇÜA algoritmaları arasındaki çeşitli tutarsızlıklar vurgulamıştır. ÇÜA algoritmasının mimari plan niteliğini arttırmak konusunda potansiyelleri tartışılmış ve değerlendirilmiştir.

Anahtar Kelimeler: ÇÜA, Mimari Plan Üretimi, Mimari Planda Nitelik, Yapay Zekâ.

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1. INTRODUCTION

Artificial intelligence (AI) has emerged as a widespread area of research with substantial effects in many sectors of the modern world. With the objective of replicating human cognitive processes, AI provides a variety of tools and methodologies to address previously unresolved problems in many fields.

Architecture, along with many other sectors, commonly uses AI. AI can utilize processes similar to architectural design, enhance design tools, generate valuable design information, and stimulate the development of new models and methodologies. Through learning processes based on predefined tasks or undefined inputs, AI can produce practical solutions customized to meet individual needs (As & Basu, 2021). AI in architecture is expected to optimize processes, facilitate extensive cooperation, and improve the intuitive and creative abilities of architects. Contemporary research trends indicate a shifting ground in traditional design methodologies, with a notable increase in AI-focused investigations in the field of architecture (Özerol & Arslan Selçuk, 2022). Primary research on AI in architecture has mostly concentrated on areas including design, performance, conservation-restoration and education. Architectural plan generation is an essential element of architectural design and has an important role in the architectural project and implementation phases. In the last few years, there has been a significant increase in the use of AI for the purpose of creating architectural plan diagrams. It is crucial to build networks that can efficiently and consistently identify and generate architectural plan diagrams. By relieving architects of repetitive duties, this will facilitate the investigation of innovative possibilities for design (Zheng & Huang, 2018).

Architectural plan generation using AI is a current research topic in the architectural literature that has been investigated using various approaches and technologies. Different techniques, such as evolutionary algorithms, expert systems, constraint-based models, decision trees, machine learning methods, recurrent neural networks (RNN), convolutional neural networks (CNN), and recently generative adversarial network (GAN) algorithms, have been used to generate architectural plans (Uzun, 2020b).

GAN (Generative Adversarial Network) algorithm has become prominent among these strategies. GAN is a type of deep learning and is considered one of the most effective machine learning algorithms for creating visual content (Goodfellow et al., 2014). Some of the applications of GANs are creating samples for image datasets, creating realistic photos, image rendering, image-to-image, text-to-image, photo-to-emoji's, photo editing, photo blending, super resolution, video prediction, 3D object creation. Although GANs have achieved great success in several domains of image generation, the process of plan generation is different. It is insufficient for the visuals produced during plan generation to merely resemble plans. They have to create rational relationships that are practical and meet the needs of their users. Plan generation is a complex procedure. GANs are only image-generation algorithms. The contradictory nature that exists in these two situations gives rise to a conflict in the assessment of the proposed strategies. Although the GAN algorithm can analyze the production output in terms of resolution, clarity, realism, and similarity to the target image (Shmelkov et al., 2018), resolution and clarity are not properties of the architectural plan, but rather define the quality of the architectural visualization (Uzun, 2020a).

The main goal of this study is to systematically analyze the quality of plan generation and assess the potential of the GAN algorithm in this regard. This investigation is based on plan generation studies with GANs. The distinctive feature of this study is its discussion and evaluation of the characteristic features of the GANs in the generation of plans. The study first discusses the concept of plan generation, the meaning of a quality plan, and then examines the GAN algorithm and plan generation studies. After that, using case studies, it offers an assessment and goes over the benefits and drawbacks of using GANs for plan generations. The study concludes by assessing the GAN algorithm's capacity to enhance architectural quality in comparison to previous research. This evaluation will provide a deeper understanding of the GAN algorithm and its impact on plan generation, while also providing crucial data for future investigations.

2. METHOD

This study conducted a literature review to assess the relationship between GANs, architectural plan generation, and the concept of quality in architecture.

This study first assesses the concept of architectural quality and establishes its relationship with the architectural plan. Afterwards, studies on plan generation with the GAN algorithm are evaluated. The selection of papers was conducted by manually examining the reference lists of the retrieved items from the electronic journal databases; Scopus, Google Scholar, and the National Thesis Center (YöKTez). The search query consisted of the following keywords: Artificial intelligent, GAN, architecture plan generation, floor plan generation, and site plan generation.

The selected studies are expected to generate architectural plans using GAN. As a result, architectural plan generation studies that did not use the GAN algorithm were excluded. As a result, 16 unique papers were included in this study. **Figure 1** shows the literature and years.

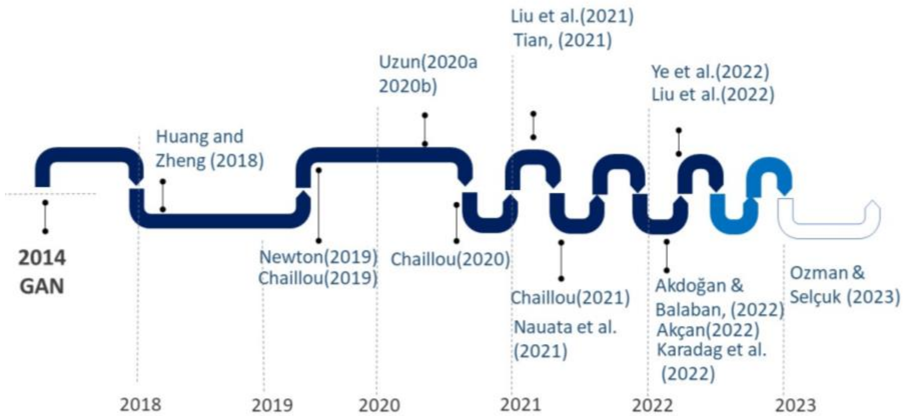

Figure 1: Number and year of studies (Figure prepared by author)

The first study on GAN and architectural plan generation was carried out in 2018. Studies have significantly increased after 2020. The studies were examined in two categories: site plans and floor plans. This literature part reviewed the generated plan diagrams, the size of the data set, and the kind of GANs.

3. THE CONCEPT OF QUALITY IN ARCHITECTURE

The concept of 'Quality' is intricate and multifaceted, making it challenging to describe. Quality can be described using adjectives like 'feature, qualification, quality, character, essence, smoothness' (Kul, 2019). Due to its difficult-to-define nature, quality is a concept that requires to be defined with adjectives and requires adjectival descriptions such as the words 'good, beautiful, excellent '(Nelson, 2017).

Nelson defines architectural quality as the degree to which a set of inherent characteristics meets specified criteria, with 'requirement' denoting a stated, inferred, or imperative need. Collectively, these definitions encapsulate the notion of 'the extent to which specific expressed, implicit, or obligatory requirements or expectations are fulfilled.' The term 'obligatory' pertains to adherence to all legal and regulatory frameworks, while 'expectations' denotes that criteria are influenced by individual perspectives (Nelson, 2017). Quality serves as an evaluative criterion based on the fulfillment of needs and expectations. Consequently, higher levels of fulfillment in architecture correlate with higher quality, rendering it both comparable and quantifiable. Nonetheless, the quality of architecture is influenced by various factors, resulting in complex needs and expectations.

The quality of the architectural cannot be considered independent of the user in this framework. Quality emerges through the user's experience of it, and therefore every experience allows quality to emerge. For this reason, although quality includes compliance with mandatory rules, laws and regulations, it is basically every 'becoming' rather than being a static value (Akın, 2006). For this reason, it is a value that reappears in different users, situations and experiences. Due to the relationship between experience and value, quality can vary from person to person, from society to society and over time. When we evaluate the definitions of quality, we can say that architectural quality should be handled in a layered framework. In **Figure 2**, the layering of architectural quality is shown diagrammatically. First of all, it must meet the requirements; it must be in compliance with statutes, decisions and regulations, and then it must meet the expectations of the user in the relationship it establishes with the user, and it must be able to receive "positive evaluations" in every encounter with the user.

Figure 2: Defining themes of Architectural Quality (Figure prepared by author)

A similar layered approach is applied to assess quality in plan generation. Architectural plan generation is primarily subject to many regulations and rules. We can assert that the most challenging aspect of architectural projects is the creation of plans. At the beginning, compliance with established protocols for plan generation is the most important element. However, complete compliance with these rules is not enough to qualify the plan. This is followed by meeting user preferences and expectations.

Therefore, the generation of architectural plans by any artificial intelligence system necessitates the consideration of these qualitative variables. Consequently, the following part of the study focuses on investigating how these qualitative criteria were approached, and to what degree the experiments with GAN were acceptable in terms of the quality of plans for architecture.

4. GANS AND ARCHITECTURE PLAN GENERATION

Computer-generated image, known as image synthesis, has experienced significant advancements in the past several years. GAN is a deep learning technique that offers exemplary results in the field of machine learning.

GAN consists of two models based on artificial neural networks. In this model, which learns through a contested process, the structure of the model consists of a generative model (Generator) that captures the distribution of the data and a discriminative model (Discriminator) that predicts the actual and generated data. The generative model enhances the interpretability of random noise data through the use of filters (kernels) and training. The discriminator evaluates the output it receives. The data is refreshed with the assessed image. The producer is moving towards generating visuals that are increasingly capable of deceiving the discriminator. The discriminative model is trained by examining both the authentic dataset and images produced by the generator. It calculates a loss value for the actual data set and a loss value for the counterfeit images provided by the generator. It assesses these values and conveys the loss value to the generator. **Figure 3** shows the working principle of the GAN algorithm(Park et al., 2021).

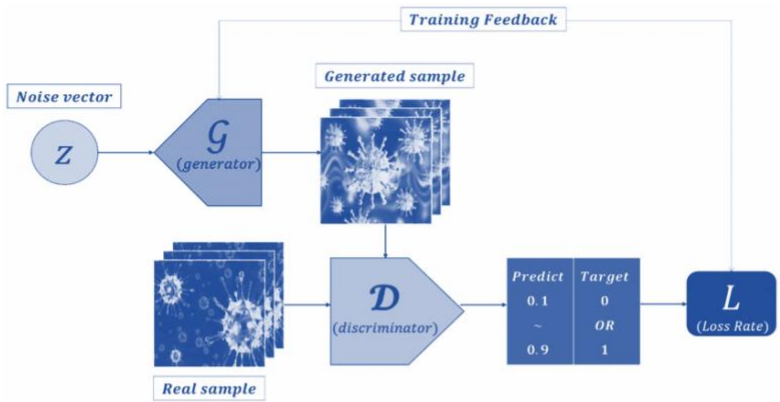

Figure 3: Working principle of the GAN algorithm (Park et al.,2021).

GAN's visual production has been widely utilized in architecture studies since its introduction in 2014 due to its success. GAN is utilized in various fields including facade design research, interior design, urban landscape, and the creation and characterization of various architectural styles through visual generation. Plan generation is also an important area studied with GAN algorithms. The study focused on examining architectural plan generating studies utilizing GAN algorithms.

4.1. Architectural Plan Generation with GANs

The majority of research on artificial intelligence and architectural plan generation is centered on autonomous plan generation. GAN is mostly utilized in various studies, such as site planning and floor plans. The studies that produce floor plans and site plans visually and pixel-based are pioneering Ai in plan generation.

In site plans, Liu et al. utilized GAN algorithms and a restricted data set to create campus site plans in the experiments on site plan generation (Liu et al., 2021). The study favored the Pix2Pix model, which is a type of GAN algorithm. The work investigates the application of deep learning on a small data set for campus layout generation, demonstrating successful outcomes despite the data limitation.

Urban design includes several factors including building layout, street block organization, orientation, density, and green space distribution. In Tian's study, they aimed to develop a model that can produce plan references for architects, landscape architects and urban designers and create a framework for design with a model that learns from the existing built environment (Tian, 2021). In their study using Pix2PixHD, GAN algorithm, 4400 different site plans were used. Visual representations were generated using Rhinoceros and Grasshopper software to interactively generate site plans. The research can be applied in concept design, rapid prototype creation, and can generate more detailed building data by utilizing numerous GAN models within the extensible framework.

Labeling during GAN training aids the algorithm in comprehending the logical connections among elements and boundaries. Liu et al. examined the design of private gardens in the southern Yangtze region in a separate study (Liu et al., 2022). The study utilized 125 unique garden layouts as a dataset. The algorithm was trained on examples of traditional Chinese private gardens, leading to the generation of private garden plans. The Pix2Pix algorithm has been developed to generate a separate garden design based on specific conditions provided in a site plan. The study is expected to assist the designer in creating concepts and developing sample schemes (Liu et al., 2022).

Developing a prototype for autonomous site plan generation is the most comprehensive initiative in the field of site plan generation. Ye et al. developed a prototype for the autonomous generation of site plans(Ye et al., 2022). Around 5000 site plans were extracted from Pinterest to develop a model named MasterplanGAN. The primary algorithm of the new model is CycleGAN. The MasterplanGAN algorithm is meant to transform monochromatic site plans into colored site plan visualizations. This study can be a valuable resource for urban designers and planners to simplify real projects and advance the automation of subjective and experience-driven processes (Ye et al., 2022).

Upon reviewing studies utilizing GAN algorithms for generating house floor plan diagrams, Zheng and Huang's research reveals as significant. In their study the Pix2PixHD algorithm was utilized, with residential housing floor plan as the dataset. The study focuses on recognizing and generating architectural drawings through machine learning. In their study, they first used machine learning to recognize and label architectural drawings and then to generate plans. Initially, a dataset of 115 plans was generated. They used 100 plans for training, whereas 15 layouts were for testing. The study investigated at how machine learning slowly learned about the features of architectural plans. The features in the graph also became clearer and more concise as the networks got deeper and the training times got longer (Zheng & Huang, 2018).

Newton's research predominantly utilizes Le Corbusier plans as the dataset, considering both limited and specialized plan-specific datasets. The main objective of the project is to comprehensively explore the use of GAN in the creation and analysis of architectural plans, particularly in connection to the works of individual architects (Newton, 2019). The study with the use of the WGAN algorithm in production did not achieve the anticipated standard of production quality. In this study shows how various dataset expansion approaches can be useful for architects dealing with small datasets (Newton, 2019).

Another comprehensive study on architectural plan generation is Chaillou's thesis. The researcher used Pix2Pix, a type of GAN algorithm, and floor plans and studied with a large data set (Chaillou, 2019). In this study, he first focused on identifying and labeling the plans. Afterwards, he diversified the plan schemes he produced in Baroque, Manhattan, Row House and Victorian styles. With the inclusion of different styles in the plan production, it was seen that production in different criteria is possible with GANs. In addition, a research was conducted to prepare the way for plan production in an interactive design environment (Chaillou, 2019, 2021). Based on the various experiments conducted in the investigations, which have advanced the study field, it has been concluded that the models examined have the capacity to be used in more intricate programs with difficult limitations. As the number of studies and examples in plan generation continues to grow, the possibility for developing practical plan generation models is also expanding steadily (Chaillou, 2019, 2021, 2022).

Uzun's studies are also one of the important studies in the field of plan generation. It was selected the DCGAN approach, a specific variant of the GAN algorithm, to undertake the task of designing and assessing architectural plans. The study conducted by Uzun et al. utilized a dataset consisting of pixel-based Andrea Palladio plans for testing purposes (Uzun et al., 2020). This paper highlights the need of comprehending the learning mechanism of the algorithm, carefully preparing the dataset, and critically assessing the outcomes generated by the Ai. This study involved the analysis of plans using qualitative and quantitative evaluations, specifically employing techniques such as space syntax, "Frechet Inception Distance" and "Fast Scene Classification" (Uzun, 2020b, 2020a; Uzun et al., 2020).

In Nauata et al.'s study, which is a comprehensive study on architectural plan generation and the quantitative and qualitative evaluation of these plans, a large data set was used (Nauata et al., 2021). In the study using the RPLAN dataset, which includes sixty thousand different plans, the room connections in the plan are shown in the form of a bubbled diagram, the rooms are color coded in the dataset and the production is expected to be done using these color codes. Afterwards, three criteria for qualitative and quantitative evaluation were determined as realism, diversity and compatibility. To assess the realism factor, both professional and beginner architects were questioned about the level of realism shown in the plans. Considering diversity, the FID score was considered, and compatibility was assessed by analyzing the graphic arrangement distances between the predicted plan and the generated plan. As a result of the study, it was stated that the study has the potential to improve an incomplete design, incorporate user input, and create alternative designs(Nauata et al., 2021).

A study by Akdoğan and Balaban explores the use of Palladian plan schemes in architectural plans (Akdoğan & Balaban, 2022). They conducted an experiment where they translated Haeckel's microorganism drawings into Palladian plan schematics. The research employing the CycleGAN algorithm can be viewed as an experiment that may stimulate next studies. Akçan utilized 150 distinct housing plans from the Ataşehir area of Istanbul as the dataset in his thesis. The dataset was categorized based on the number of rooms in the floor plans. The study revealed that data sets belonging to a specific category yielded more consistent findings. The study highlights the significance of developing datasets and the challenges involved. It suggests that local and administrative governments should adapt their databases to facilitate AI research and enhance its effectiveness (Akçan, 2022).

Karadag et al. created a machine learning model named EDU-AI using the GAN. The study also utilized the Pix2Pix algorithm. 144 classroom plans were reviewed, a structure for utilizing GAN was established, and a two-layer learning model was created (Karadag et al., 2022).

Study	Data set -type	GANs
Liu vd.,(2021)	Campus plans (387 examples)	Pix2Pix
Tian, (2021)	Site plan (4400 data, 4000 training and 400 validation)	Pix2PixHD
Liu vd.,(2022)	Garden plans (125 data 120 training and 5 validation)	Pix2pix
Ye vd.,(2022)	Site plans (5000 data)	CycleGAN
Huang and Zheng (2018)	Housing floor plans (115 data, 100 training, 15 validation)	Pix2PixHD
Newton(2019)	Le Corbusier plans (45, 135 ve 180 data)	WGAN
Chaillou(2019,2021,2022)	Housing floor plans (more than 800 data)	Pix2Pix
Uzun(2020a, 2020b)	Paladian Plans (125 data)	DCGAN
Nauata vd.(2021)	Housing floor plans (60.000 data)	CGAN
Akdoğan & Balaban, (2022)	Paladian Plans (100 data) Haeckel's drawings (105 data)	CycleGAN
Akçan(2022)	Housing floor plans (150 data)	Pix2Pix
Karadag vd. (2022)	Classroom plans (162 data, 144 training 18 validation)	Pix2pix
Ozman & Selçuk (2023)	TOKI plan typologies (157 data)	DCGAN

Table 1: Studies on floor plan and site plan generation using GANs.

Ozman and Selçuk (2023) utilized 21 TOKI plan typologies as a dataset in their investigation. The dataset was augmented into 157 plans and DCGAN was utilized. Visual results were not achieved after 500 epochs in the DCGAN. The study also tested a larger dataset, HouseGAN LIFULL HOMES. The study highlighted the significance of dataset size, stating that with a significant dataset, plans can be utilized more systematically and functionally (Ozman & Selçuk, 2023). The studies on site plan and floor plan generation using the GAN algorithm are summarized in the table (Table 1) above, taking into account the methods used, data set and year.

In 2018, the initial instances of planned generations emerged, and they are already seeing significant growth. This study offers a brief assessment and identification of issues regarding the plans generated using GANs.

4.2. Brief Evaluation of Plans Generation with GANs

Over the past five years, a multitude of studies have been conducted on plan generation within controlled settings, significantly advancing the capabilities of GAN algorithms and plan generation methodologies. Many studies on plan generation prioritize the selection of residential plans due to the relative ease of obtaining datasets compared to other plan typologies.

In the light of the reviewed literature, it is seen that Pix2Pix, DCGAN and CycleGAN algorithms are the most prominent algorithms in plan generations. The increased prevalence of these algorithms can be attributed to their enhanced usability and compatibility with architectural plans.

The process of generating the dataset is a pivotal stage in GAN-based research. Enhanced accessibility to datasets facilitates progress in subsequent stages of investigation. Expansion of the small dataset, among other tasks, is a crucial aspect of research based on GANs. Due to its nature as an image and dataset-based generation method, the quality of the outputs is directly influenced by the dataset it is provided.

Most of the studies analysed included the generation of the plan up to the point of acquiring the image. While the possible applications of the plan are acknowledged, the majority of the studies fail to address the quality or usability of the plans (Chaillou, 2019; Newton, 2019; Ozman & Selçuk, 2023; Zheng & Huang, 2018). The quality of the generated plan is more crucial than the quality of the image. Research on architectural plan creation highlights the necessity for novel assessment methods for assessing the GAN algorithm for architectural plan generation (Chaillou, 2022; Nauata et al., 2021; Uzun, 2020b). Research indicates that quantitative evaluation methods in GAN assessment prioritize visual quality and lack the necessary depth for generating plans. There is limited research on qualitative evaluation methods for designs created by GANs. The research primarily investigate the authenticity of plans created by participants, aiming to differentiate between plans generated by GANs and those created by humans (Nauata et al., 2021; Uzun, 2020a).

This study posits that the determination of authenticity hinges on specific criteria, which necessitates further exploration through research on architectural quality. The dependence of GANs on a dataset, as well as the fact that their production is only visually based and unstructured, creates a conflict with the plan generation process.

5. DISCUSSION

The quality of plan generation is derived from a multi-layered procedure. This study highlights various inconsistencies between the nature of plan generation and the GAN algorithms.

- Plan generation facilitated by GANs yields visual outputs without adhering to a layered framework. While visuals may suffice in certain contexts, they fall short in addressing legal compliance, user expectations, and spatial coherence, all of which are crucial in plan preparation. The primary objective of plan production extends beyond mere visual representation. Thus, rule-based productions, in which the GAN generates only a portion of a plan rather than its entirety, are regarded as more effective (As et al., 2018; Karadag et al., 2022; Wu et al., 2019). For instance, Wu et al. show a rule-based progress. The living room is the first to be positioned with the learning network that has been built, based on the observation that the living room is present in nearly all floor plans. It then continues by generating other rooms. The study performs better than current methods since it is layered and rule-based (Wu et al., 2019).

- Due to the hallucinogenic nature of the creations in the GAN, it is not feasible to apply specific criteria across the areas as the productions rely on the dataset's properties. Most studies on plan generation using GANs have mostly concentrated on the plan-generating stage. Exploring or modifying the nature of plan generation has become less of a priority. However, as technology and algorithms continue to improve and their boundaries are being investigated, it is increasingly probable that plan quality will become a central area of study in the next few years.

- A significant drawback lies in the pixel-based nature of GAN-produced images. Pixel-based outputs have yet to gain traction in architectural practice due to the reliance on extensive datasets and limitations in post-production utility (Deprez et al., 2023). This presents a major drawback of GANs in plan generation. Due to the fact that architectural designs are rarely implemented and developed on a pixel-by-pixel basis.

- Another disadvantage is the requirement for extensive data sets. Research with GANs has shown that an increase in the number of samples in the dataset leads to more sophisticated outputs (Zheng & Huang, 2018). Plan generation does not consistently follow same criteria in all locations. For instance, regional contributions can vary because of climate or cultural influences. Accessing large data sets is not always possible.

In architecture, plan generation is expected to meet both quantitative and qualitative standards. Architectural plan generation is a complex process that involves considering various criteria such as spatial organizations, technical limits, and consumers' perception, ultimately relying on creativity. Considering the layered structure of quality for future studies, it is thought that the productions made with AI should also model this layered framework. A thorough examination of quality in the architectural plan generation is necessary to enhance AI applications and represent qualitative attributes. This research should be conducted using a comprehensive methodology that incorporates both qualitative and quantitative research methods.

6. CONCLUSION

Generating architectural plans using artificial intelligence presents a contemporary challenge. This study underscores the limitations of the GAN algorithm, which has gained prominence in plan generation in recent years, particularly in terms of quality. The GAN algorithm is known for its effectiveness in image-generating tasks, but its actual implementation in plan generation is still limited. Although studies on plan generation with GANs are crucial, only the GAN algorithm is insufficient. Artificial intelligence is widely recognized as pivotal for the future of architecture. In the coming years, inquiries such as "Can machines be taught architecture?" "To what extent can machines acquire architectural knowledge?" and "To what degree can machines produce high-quality architectural design?" will be revisited and further investigated. To advance research in this field, the development of a comprehensive methodological framework that evaluates both qualitative and quantitative capabilities is imperative.

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Conflict of Interest Statement

The authors of the study declare that there is no financial or other substantive conflict of interest that could influence the results or interpretations of this work.

Author Contribution

Author Contribution The authors declare that they have contributed equally to the manuscript

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