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COMPARATIVE ANALYSIS AND COLLABORATIVE INNOVATION OF PARAMETRIC GENERATION AND AIGC

***Purpose**. The purpose of the article is to conduct a comparative analysis of the characteristic features, advantages, and limitations of parametric design and AIGC in the context of potential opportunities for joint innovation and achieving synergistic effects.*

***Methodology**. The theoretical and methodological basis of the study was formed by such general scientific approaches as comparative and systemic approaches, which made it possible to carry out a comparative analysis of parametric design and AIGC and to imagine their integrity; the structural-functional approach made it possible to analyze the patterns and principles of the functioning of parametric design and AIGC in the context of potential opportunities for joint innovations.*

***Results**. The study results have theoretical and practical significance, which consists of expanding the application of parametric generation and artificial intelligence in design, focusing on their functional characteristics and areas of application. A comparative analysis of parametric design and artificial intelligence was carried out through technical principles, tools, generation stages, designer involvement, aesthetics, and creativity, and their features, strengths, and limitations were analyzed. Approaches such as transitioning from parametric design to artificial intelligence were proposed to achieve a synergistic effect. It was emphasized that parametric design can stimulate the creation of artificial intelligence. In contrast, artificial intelligence can help in conceptual design, obtain parameters, support parametric models, and serve as input data for parametric models. It was found that artificial intelligence can also evaluate and refine parametric generation results. It is concluded that parametric design and artificial intelligence complement each other, have significant potential for joint innovations in the design field, and their simultaneous use allows for a synergistic effect.*

***Scientific novelty.** The article conducts a comprehensive comparative study of the parametric generation and AIGC technologies from various perspectives, including technical principles, design tools, different stages of the generation process, the role and participation of designers, aesthetics, and creativity. It identifies the strengths and corresponding limitations of parametric modeling and AIGC and proposes new approaches to their use in the field of design and achieving a synergistic effect.*

***Practical significance.** The results obtained lead to a deeper understanding of such modern phenomena as parametric generation and AIGC, which allowed us to develop practical recommendations for their systematic use in the field of design, for the development of new design tools and design processes.*

***Keywords:** design, modeling, generation, parametric design, annual analysis, innovation, digital technologies, graphic design.*

Introduction. Parametric design, rooted in computational logic and mathematical models, excels in solving complex design challenges with precision and adaptability [2]. Its ability to adjust parameters enables exploration within defined constraints, yet it can sometimes limit spontaneous creativity due to its reliance on predetermined algorithms. AIGC technology offers tools for producing imaginative and diverse design outcomes, expanding creative possibilities [1]. However, these methods often struggle to maintain control and coherence with specific design objectives.

Bridging the gap between the structured precision of parametric design and the creative versatility of AIGC methods represents a significant opportunity and challenge in generative design. By combining the strengths of both approaches, this collaboration aims to enhance innovation, efficiency, and control ability within design processes.

Analysis of previous studies. Parametric generation, as an algorithm-assisted design approach, is centered on the establishment of parameter variables and rules to generate dynamic design outcomes that exhibit a degree of logic and complexity in real time. This method not only addresses challenges associated with repetitive tasks and rapid changes in the design process but also fosters computational creativity, enabling designers to explore a broader range of design possibilities [15]. Originally emerging and gaining widespread application in architectural design, parametric design has since been extensively adopted in fields such as product design, fashion design, and concept art. In the context of graphic design and generation, parametric generation represents a significant aspect of digital generation technologies.

Oxman R. explored the uniqueness of the concept of parametric design and its influence on models of parametric design thinking (PDT), tracing the evolution from early cognitive models to contemporary paradigms of parametric design thinking [11]. Another study [2] integrated the formal rules of traditional patterns with parametric design methods, extracting compositional principles from traditional pattern forms and employing function curves and control point coordinates in modern graphic design for parametric reconstruction. By adjusting variable parameters, the target patterns underwent a series of transformations and derivations, enriching the formal possibilities of traditional motifs. Similarly, a paper [12] introduced a method and practical application for the parametric generation of Islamic geometric ornaments, highlighting the relationship between parametric techniques and the mathematical structure of Islamic patterns. The authors utilized software to create a model and its basic grid structure, facilitating an exchange between traditional cultural heritage and modern technologies.

Generative models have a long history in artificial intelligence, dating back to the 1950s. AIGC (AI-Generated Content) refers to a paradigm in which content is generated using advanced generative artificial intelligence (GAI) technologies rather than being created by humans. Guided by human-provided instructions, AIGC models are capable of learning and interpreting generative tasks, leveraging GAI algorithms to automatically produce large volumes of content aligned with the input prompts within a short period. The advent of deep learning has significantly enhanced the performance of generative models, with the emergence of Generative Adversarial Networks (GANs) marking a milestone in AI-driven image generation. Currently, AIGC focuses on generating multimodal content, supported by foundational generative models such as vision-language models, text-audio models, text-image models, and text-code models. AI can also be employed for artistic creation, including the imitation and reinterpretation of specific artistic styles. However, it should be noted that AI does not always accurately capture user intentions, and there is an inherent degree of uncertainty in its outputs. Continuous updates to datasets, along with ongoing learning and retraining, are essential for maintaining the creative capacity of AIGC systems [1].

AIGC has become a significant focus in the field of design research. The paper [6] highlights that, in the realm of graphic design, AIGC tools can serve as a source of inspiration for designers, enabling the rapid generation of numerous creative concepts and drafts. Moreover, these tools introduce new possibilities in design thinking, facilitating the exploration of diverse styles and combinations of design elements. Additionally, AIGC can automate repetitive tasks, significantly improving the efficiency of routine design work.

The article [16] examines the integration of AIGC with graphic design, identifying four research paradigms: AI-Driven Design Automation and Generation (AIDAG), AI-Assisted Graphic Design and Image Processing (AGDIP), AI in Artistic and Creative Design Processes (AACDP), and AI-Enhanced Visual Attention and Emotional Response Modeling

(AVERM). Wu et al. explore the mechanisms by which AIGC supports the design process across four stages: creative ideation, design generation, assistance and recommendation, and evaluation and feedback. Lou [9] addresses the question of creativity in the AI era, emphasizing that the ability to create meaning remains, and will continue to be, a distinct advantage of human creativity. Human ingenuity must transcend the limitations of computational rationality. The paper [7] compares traditional creative methods with AIGC-based approaches, concluding that traditional methods often demonstrate greater creativity.

In terms of application, Ma et al. [10] utilize AIGC technologies to generate designs for traditional Chinese characters, presenting a complete workflow for this process. The paper [8] details the application of AIGC in game design, employing image extraction and generation models to achieve efficient character design. Yu [17] emphasizes the importance of user experience in optimizing the application of AIGC tools. Gao [3] notes that in the animation industry, AIGC has the potential to revolutionize character and scene design, plot development, and scriptwriting, driving transformative innovation across the sector.

AIGC and parametric generation are both pivotal tools and methods in the era of digital design, each with its own advantages and limitations. The exploration of their integration has become increasingly essential and is already underway. Parametric design tools can be combined with neural networks, including ANN and CNN, to generate complex models. The collaboration between these approaches has the potential to introduce new possibilities in design automation, optimization, and decision-making [13]. Hegazy M. highlights the powerful ability of AI to generate abstract conceptual designs, while parametric design, rooted in mathematics and algorithms, enables the creation of limitless design possibilities. The integration of these two approaches holds immense potential. The author emphasizes that AI should be applied within frameworks that prioritize human-centeredness, environmental responsibility, and cultural sensitivity [4]. The paper [14] proposes a method for enhancing data-driven parametric modeling systems using machine learning, addressing the limitations of traditional systems in design exploration. The researchers employ recurrent neural networks to generate alternative data flow diagram paths, providing innovative approaches for exploring the topological structures of parametric models.

Statement of the problem. Both parametric generation and AIGC are important design generation technologies, each with its own unique advantages and characteristics. However, there is a lack of systematic analysis and organization of these features. While both technologies offer distinct benefits, it remains unclear how they can be effectively integrated to leverage their respective strengths. The key challenge lies in determining the appropriate pathways and directions for their collaboration, identifying specific stages of the design process where their advantages can complement each other. Understanding how these technologies can be combined to create innovative design methods and tools is of significant importance. Such integration could lead to enhanced creativity, efficiency, and control in design, ultimately providing a more robust framework for future design practices.

Research results and discussion. The purpose of the article is to conduct a comparative analysis of the characteristic features, advantages, and limitations of parametric design and AIGC in the context of potential opportunities for joint innovation and achieving synergistic effects.

Comparative Analysis of Parametric Generation and AIGC. Both parametric modeling and AIGC technologies are capable of generating design outputs, particularly in the creation of patterns and graphics. While these two approaches share certain commonalities in addressing design generation challenges, they also exhibit significant differences. This analysis explores their distinctions and similarities across several dimensions, including technical principles, design tools, generation processes, designer involvement and tasks, and creativity and aesthetics. The goal is to elucidate the characteristics of each method in design generation and identify opportunities for complementary integration and innovative convergence.

Parametric design and AIGC rely on distinct computational technologies. Parametric design is grounded in algorithmic and logical operations, utilizing precise mathematical models and geometric computations, such as NURBS curves and Boolean operations. The precision and adjustability of parameters enable immediate and responsive design changes, emphasizing logic, structure, and control. This makes parametric design particularly suited for tasks requiring high accuracy and clearly defined functional goals.

A quintessential example of parametric design tools is Grasshopper (GH), an integrated plugin for Rhino, which is widely applied across various design fields. GH facilitates tasks such as geometric form generation, digital simulation, design optimization, and digital fabrication. Generative Components (GC), developed by Bentley Systems, shares similar principles and workflows with GH, having been an earlier innovation that inspired Grasshopper's development. Another prominent tool is Dynamo, tightly integrated with Autodesk Revit, which is primarily used in architectural design. These software platforms typically employ visual programming techniques, utilizing nodes and modules to construct parametric models and algorithms, thereby achieving specific design objectives.

AIGC relies on deep learning and generative models such as GANs, Transformers, and diffusion models. By training on extensive datasets, these models enable the creation of multimodal content, including text, images, audio-visual materials, and 3D objects. Deep learning is a technology grounded in multi-layered neural networks that automatically extract features from large-scale data and perform complex tasks. The foundation of AIGC lies in employing pattern recognition and generative learning techniques on input data to produce creative content that meets specific requirements. The continuous improvement of model algorithms, the expansion of foundational models, and access to high-quality datasets are key factors driving the advancement of AIGC technology.

Currently, widely used AIGC tools include Open AI's DALL-E, MidJourney, and Stable Diffusion. Open AI's DALL-E, supported by large language models, generates images based on users' natural language descriptions. Similarly, MidJourney and Stable Diffusion also possess the capability to produce images from textual descriptions and can further generate images based on existing ones. MidJourney employs techniques akin to GANs, focusing on the generation and processing of graphical and artistic images, allowing for the creation of images with specific artistic or stylistic attributes. Stable Diffusion, a highly versatile AI-driven creative tool, excels at generating new images from existing ones. It facilitates style transfer, content extension, and localized adjustments, enabling users to refine, transform, or expand visual content effectively.

A complete generative creation process can be divided into several stages: input, processing, output, and evaluation feedback. In parametric generation, designers need to establish clear rules and define input parameters. These parameters can include various types of data, such as geometric objects, numerical values, text, images, or files. In the context of AIGC technology, using MidJourney as an example, users typically input descriptive text or images to specify and guide the desired output. At the current stage of development, parametric generation offers a wide variety of input types, providing designers with considerable flexibility. In contrast, the input methods for AIGC are relatively straightforward and simplified, focusing primarily on direct textual or visual descriptions.

In the processing stage, parametric models function as open systems, with the modeling work constructed entirely by the designer. The designer interacts with the constructed model by adjusting parameters to explore and refine the design. This approach not only requires designers to possess strong geometric modeling skills but also demands advanced logical thinking abilities and a solid foundation in programming. As a result, the overall skill requirements for users are relatively high, and the cognitive cost of using such systems can be significant. AIGC technology addresses generative tasks by relying on pre-trained large-scale models provided by service providers. Designers interact with these models by inputting natural language descriptions or images, allowing for intuitive and seamless communication with the system. This interaction method is more direct, user-friendly, and accessible, making it significantly easier to learn and use.

From the perspective of output results, parametric generation exhibits strong geometric regularity and logical characteristics, often characterized by high symmetry, repetition, and precision. The outputs are highly targeted and are frequently applied to meet specific functional requirements, such as structural or spatial demands. Although elements of randomness can be introduced during the process to create forms that surpass conventional imagination, the overall process remains under logical control. Designers can interact with the generated outputs by adjusting input parameters, iteratively refining results until achieving a satisfactory design. This method allows for precise control and fine-tuning of the design outcome. By contrast, the most notable features of AIGC-generated results are their richness in diversity and creativity, along with a degree of unpredictability. These outputs often resemble artistic styles and sources of inspiration, offering strong visual appeal and impact. As such, they are predominantly suited to unstructured creative design tasks, such as conceptual art design. However, it is important to note that AIGC-generated results inherently involve a level of uncertainty. Each generation may significantly deviate from the designer’s intended goals, requiring iterative adjustments to reduce discrepancies. Despite repeated refinements, it remains challenging to ensure that the generated results align precisely with the designer's expectations. Furthermore, data biases can limit the control and precision of AIGC-generated outputs.

In the evaluation and feedback stage, parametric generation results can not only undergo subjective assessment but, more importantly, be evaluated systematically and precisely based on predefined design objectives and quantitative metrics, such as strength, area, or other measurable criteria. Designers can directly adjust parameters to implement feedback, allowing them to clearly and dynamically monitor changes in the design outcomes in real time. The underlying technical principles of AIGC result in the generative process being carried out within a "black box" system that is not accessible to designers. Designers are provided only with the final outputs, which are visually impactful but inherently uncertain due to the unpredictable nature of the generative process. Evaluation is predominantly based on the user’s subjective aesthetic judgment, lacking standardized or consistent quantitative criteria. Adjustments and refinements of AIGC-generated results rely on iterative user inputs to modify and improve outcomes. However, this approach is often indirect and lacks the precision and control afforded by parametric generation.

The level of designer involvement and the nature of their tasks vary significantly between these two generative approaches. In parametric modeling, designers must participate deeply in all stages of the design process, carefully considering design requirements and related factors. A critical aspect of their work involves determining the types and quantities of design parameters and constructing logically rigorous generative algorithms. Designer's act both as rule-makers and as controllers of the generated results, engaging in intensive interactions with parametric models to modify and optimize the outputs. Successfully completing such tasks requires a high level of expertise and a comprehensive knowledge base, including advanced design skills, algorithmic thinking, coding and programming proficiency, and foundational understanding of computer vision.

When using AI to participate in generative design tasks, designers provide prompts or images to pre-trained large models to guide the direction of the generated results. However, their involvement is relatively superficial compared to parametric modeling, as they cannot fully control every detail of the design process. Instead, designers can only propose modifications based on the generated outputs or select from multiple results. The quality and expressiveness of the outcomes rely heavily on the capabilities of the closed model itself, with the designer functioning primarily as a guide who partially influences the inherently uncertain output. On the other hand, this also means that designers can easily adopt AIGC tools, allowing them to quickly and flexibly generate a large volume of visually distinctive design outcomes.

The creativity of parametric generation stems from the designer's subjective ideas and the logical framework of rules they define. Its adherence to rules makes it particularly effective for exploring complex geometric forms and addressing functional requirements with precision. This approach allows for the accurate representation of intricate relationships within design and precise control over outcomes. However, its reliance on parameters and rules often results in predictable and structured creativity. The generated visuals typically exhibit complexity, logical coherence, natural forms, and geometric patterns.

In contrast, AIGC derives creativity from minimal designer input, pre-trained large models, and diverse datasets. Simple prompts enable AI to generate novel and diverse visuals akin to inspiration-driven processes, often surpassing expectations. However, its reliance on static datasets can limit adaptability and timeliness, and biases or gaps in the data may affect quality and inclusivity. While AIGC excels in recognizing patterns and producing diverse, expressive outputs, it struggles with originality beyond its training data. Its results are marked by strong visual impact, stylistic variety, and emotive creativity but lack precise control and goal-oriented constraints.

2. Collaborative Innovation Pathways

Parametric design, with its rigorous logic and structured generative characteristics, provides precise and systematic solutions for addressing complex design problems. It enables designers to explore design spaces more efficiently and tackle intricate forms and functional optimizations that are difficult to achieve through traditional manual methods. Artificial intelligence, particularly generative AI (AIGC), excels at addressing complex and unstructured issues such as semiotics and semantics. With its powerful data processing capabilities and highly innovative generative potential, AIGC offers designers a broad range of inspirational sources and multidimensional design options. By integrating the "rule-based generation" features of parametric design with the "inspiration-driven creation" capabilities of AI, it is possible to establish an entirely new design paradigm that transcends the boundaries of traditional design. This integration has the potential to profoundly impact the role of designers, the methodology of design, and the overall design process. It combines creativity and structure to provide dual pathways for solving complex design challenges, merging innovative ideation with systematic problem-solving.

Integrating parametric design with AI-generated content (AIGC) offers a novel approach to design innovation. By using outputs from parametric models as inputs for AIGC systems, designers can enhance the diversity and creativity of design solutions. This method allows for the generation of a wide array of design alternatives, each reflecting unique characteristics derived from the original parametric configurations. Such integration not only broadens the spectrum of design possibilities but also provides designers with valuable insights and inspiration, thereby streamlining the creative process. For instance, a designer might create a series of grid patterns using parametric tools and then input these patterns into an AIGC model to produce innovative variations. This collaborative approach leverages the strengths of both parametric precision and AI-driven creativity, leading to more dynamic and adaptable design outcomes.

Parametric design systems encompass a comprehensive framework, including stages such as conceptual design, parameter extraction, algorithmic model construction, output generation, and iterative optimization. AIGC can be integrated into various stages of the parametric design process, leveraging its robust generative capabilities to support and expand creative possibilities within parametric workflows.

AIGC can drive parametric conceptual design by generating initial concepts and ideas, which are then executed through parametric modeling. During the conceptual design phase, AI tools enable designers to quickly produce creative textual descriptions and graphical examples for reference. These outputs offer inspiration and potential directions for parameterized concepts, guiding the establishment of design rules and algorithmic modeling. The visual concepts generated by AI allow designers to evaluate and anticipate potential outcomes before embarking on labor-intensive modeling work. This foresight reduces trial-and-error costs later in the process, thereby enhancing efficiency. For instance, a designer could use AI to generate a set of creative graphical concepts, select a promising direction, and proceed with parametric modeling based on that choice.

AIGC can assist in the determination and extraction of parameters. Through advanced analysis of complex design data, AI models can deconstruct intricate design relationships, identifying and extracting critical parameters. By leveraging semantic analysis, these models clarify the intrinsic connections between parameters, thereby significantly reducing the workload for designers in organizing parameters and enhancing the precision of model construction. This process aids in unraveling complex design logic and swiftly pinpointing key elements directly related to design objectives. For example, when working on a particular type of pattern design, AI can analyze the shared geometric features of the patterns and suggest potential control parameters, offering valuable references for designers.

AIGC can assist the process of parametric modeling. AI possesses the capability to generate code and demonstrates a strong understanding of commonly used algorithms and logic. It can provide insights into constructing parametric algorithms, retrieve similar algorithms and models for designer reference, and even directly generate portions of code to be integrated into parametric models. With increasing levels of intelligence, AI may even be capable of creating entire parametric models, enabling precise generation and control of design outcomes. Furthermore, AI can optimize and refine pre-built algorithmic models. Imagine a scenario where AI tools are seamlessly integrated into parametric design software. Designers could leverage AI to generate efficient algorithmic code or access pre-existing algorithm modules. This integration would substantially lower the technical barriers and complexity of parametric modeling, making the process more accessible and efficient.

AIGC-generated outputs can serve as inputs for parametric design. The results produced by AI often exhibit distinct stylization, creativity, and unpredictability. When these outputs are integrated into parametric models and subjected to logical computational processes, they can yield precise final results with unexpected effects. The logical operations of parametric design refine and detail AI-generated content, achieving a balance between creativity and precision, as well as between artistic and logical aspects. This integration enhances the practicality and functionality of the generated solutions. For instance, a complex image generated by AI can be imported into a parametric model as input, producing innovative and unique effects that can be further adjusted and controlled.

AI can evaluate and refine parametric design outputs. Parametric results are often convincing in functionality but weaker in assessing artistic style or cultural semantics, relying mainly on designers' subjective judgment. By using AI to analyze and compare outputs, it is possible to identify designs that meet requirements in culture, semantics, or style, helping to quickly select options that align with overall design goals. For example, in stylistic design, AI can rank designs based on predetermined aesthetic standards, improving evaluation consistency. AI can also assist in refining outputs, ensuring better alignment with artistic and functional needs.

Conclusions. Through a comprehensive and systematic comparative analysis of parametric design and AIGC from perspectives such as technical principles, design processes, designer tasks, creativity, and aesthetics, it is evident that both technologies possess strong design processing capabilities, yet each has its limitations. Parametric design faces constraints in creativity and flexibility, while AIGC is prone to uncertainty and inconsistency in generation. However, the strengths of both technologies complement each other effectively, and their collaboration can overcome these limitations. By exploring the pathways from parametric design to AIGC and vice versa, opportunities for systemic innovation between them are revealed. Parametric outputs can serve as inputs for AIGC, and AIGC can assist in extracting design parameters, constructing models, and evaluating results, as well as providing input for parametric models. Future research will focus on implementing these pathways through design practice and validation, alongside the development of tools and design processes, aiming to create a new digital generative design paradigm.

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ПОРІВНЯЛЬНИЙ АНАЛІЗ ТА СПІЛЬНІ ІННОВАЦІЇ ПАРАМЕТРИЧНОЇ ГЕНЕРАЦІЇ ТА ШТУЧНОГО ІНТЕЛЕКТУ

Мета: *провести порівняльний аналіз характерних особливостей, переваг і обмежень параметричного дизайну та штучного інтелекту в контексті потенційних можливостей спільних інновацій та досягнення синергетичного ефекту.*

Методологія. *Теоретико-методологічною базою дослідження стали такі загальнонаукові підходи, як-от: компаративний та системний підходи, що дали можливість здійснити порівняльний аналіз параметричного дизайну та штучного інтелекту та уявити їх цілісність; структурно-функціональний підхід дозволив проаналізувати закономірності й принципи функціонування параметричного дизайну та штучного інтелекту в контексті потенційних можливостей спільних інновацій.*

Результати. *Результати дослідження мають теоретичну та практичну значимість, що полягає у розширенні застосування параметричної генерації та штучного інтелекту у дизайні, зосереджуючись на їхніх функціональних характеристиках та сферах застосування. Проведено порівняльний аналіз параметричного дизайну та штучного інтелекту через технічні принципи, інструменти, етапи генерації, залучення дизайнерів, естетику та креативність, проаналізовано їхні особливості, сильні сторони та обмеження. Запропоновано підходи, які дозволять досягти синергетичного ефекту, наприклад перехід від параметричного дизайну до штучного інтелекту і навпаки. Наголошено, що параметричне проєктування може стимулювати створення штучного інтелекту, тоді як штучний інтелект може допомогти в концептуальному проєктуванні, отримувати параметри, підтримувати параметричні моделі та служити вхідними даними для параметричних моделей. З'ясовано, що штучний інтелект також може оцінити та уточнити* *параметричні результати генерації. Висновувано, що параметричний дизайн та штучний інтелект взаємодоповнюють один одного, мають значний потенціал для спільних інновацій у сфері дизайну, а одночасне їх використання дозволяє досягти синергетичного ефекту.*

Наукова новизна. *У статті проведено комплексне порівняльне дослідження параметричної генерації та технологій штучного інтелекту з різних точок зору, включаючи технічні принципи, інструменти проєктування, різні етапи процесу генерації, роль і участь дизайнерів, естетику та творчість. Виявлено сильні сторони та відповідні обмеження які існують в параметричному моделюванні та штучному інтелекті, запропоновано нові підходи їх використання в сфері дизайну.*

Практична значущість. *Отримані результати зумовлюють більш глибоке осмислення таких сучасних явищ як параметричні генерації і штучний інтелект, що дозволило розробити практичні рекомендації їх системного використання у сфері дизайну, а також для розробки нових дизайнерських інструментів та процесів проєктування.*

Ключові слова: *дизайн, моделювання, генерація, параметричний дизайн, річний аналіз, інновації, цифрові технології, графічний дизайн.*

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