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GENERATIVE ARTIFICIAL INTELLIGENCE FOR AUTOMATED DESIGN OF ENGINEERING STRUCTURES

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ABSTRACT

Generative artificial intelligence (Generative AI) is emerging as a transformative technology in engineering design, offering new opportunities to automate structural development, improve design efficiency, and explore innovative engineering solutions. Traditional structural design processes often require repeated calculations, manual modelling, and extensive evaluation to achieve suitable performance, safety, and cost objectives. Generative AI techniques, including generative adversarial networks, variational autoencoders, diffusion models, and large language models, can support the generation and refinement of structural design alternatives based on specified requirements and engineering constraints. These technologies have potential applications in building structures, bridges, lightweight components, material-efficient systems, and complex geometries. Recent research on AI-assisted engineering design and generative design demonstrates opportunities for improving design exploration, computational efficiency, and engineering creativity (Wu et al., 2023; Wang et al., 2024). This article examines the role of generative artificial intelligence in automated structural design through a qualitative review of existing scholarly literature. It explores major applications, potential benefits, technical limitations, and requirements for practical implementation. The review indicates that generative AI can help engineers explore multiple design alternatives, reduce repetitive modelling tasks, and support material-efficient structural solutions. However, structural safety, physical feasibility, data limitations, interpretability, and regulatory compliance remain essential concerns. The study concludes that generative AI should complement established engineering analysis and validation rather than replace professional engineering judgment.

KEYWORDS

Generative Artificial Intelligence, Automated Structural Design, Engineering Structures, Generative Design, Structural Optimization, Deep Learning, Computational Design, Engineering Innovation

INTRODUCTION

Engineering structures are designed to satisfy demanding requirements involving strength, stability, serviceability, durability, material efficiency, and economic feasibility. Traditional structural design relies on established engineering principles, mathematical calculations, numerical simulations, and repeated revisions to achieve suitable performance. Although these methods provide reliable foundations for engineering practice, complex structures and multiple design constraints can make the design process computationally intensive and time-consuming. Generative artificial intelligence introduces new opportunities by learning patterns from engineering data and generating alternative design concepts that satisfy specified requirements.

INTERNATIONAL JOURNAL OF APPLIED AI IN ENGINEERING SCIENCES

Vol.01-01-2026 E ISSN:XXXX-XXXX P ISSN:XXXX-XXXX

Wu et al. (2023) examined generative artificial intelligence in scientific research and highlighted its potential to support knowledge-intensive tasks while emphasizing the importance of reliability and verification. In structural engineering, these capabilities may help engineers explore a wider range of design alternatives and improve the efficiency of early-stage design development.Generative AI differs from conventional optimization methods because it can learn representations of existing designs and generate new candidates rather than simply selecting solutions from a predefined set. Techniques such as generative adversarial networks, variational autoencoders, and diffusion models can produce design geometries, structural configurations, or material arrangements based on learned patterns. These methods may support the development of lightweight components, complex structural forms, and alternative load-bearing configurations. Wang et al. (2024) discussed advances in generative AI and its wider technical capabilities, providing a foundation for considering how generative models can support engineering design workflows. However, generated designs must be evaluated against engineering requirements, since visual plausibility does not guarantee structural strength, stability, or practical manufacturability.

Automated structural design also depends on integrating generative models with computer-aided design, finite element analysis, numerical optimization, and simulation tools. A generative model can propose a structural configuration, while engineering software evaluates its response to loads, boundary conditions, material properties, and environmental demands. Results from simulation can then guide subsequent design revisions. This process can establish an iterative workflow in which AI-generated alternatives are assessed and refined through engineering analysis. Research on generative design and computational engineering indicates that combining automated generation with performance evaluation can expand design exploration and reduce some repetitive modelling tasks (Wu et al., 2023; Wang et al., 2024). Nevertheless, the effectiveness of such workflows depends on accurate models, suitable constraints, and reliable evaluation procedures.Material efficiency and sustainability are additional motivations for adopting generative AI in structural engineering. Conventional structures may contain excess material because of conservative design choices, limited exploration of alternatives, or manufacturing constraints. AI-assisted design can explore alternative geometries and structural arrangements that aim to meet performance requirements with more efficient material distribution. Potential applications include trusses, beams, building components, bridge elements, and lightweight mechanical structures. Such approaches may contribute to reduced material consumption and lower environmental impacts when the generated solutions are validated and manufactured appropriately. However, sustainability cannot be assessed through material reduction alone; durability, maintenance, production energy, construction methods, and the complete life cycle of a structure must also be considered.

Despite these opportunities, generative AI introduces significant technical and professional challenges. Models trained on limited or unrepresentative datasets may generate structures that

INTERNATIONAL JOURNAL OF APPLIED AI IN ENGINEERING SCIENCES

Vol.01-01-2026 E ISSN:XXXX-XXXX P ISSN:XXXX-XXXX

are unsuitable for particular loads, materials, or environmental conditions. Generated designs may also contain geometric irregularities, unsupported connections, or configurations that violate engineering codes. In addition, complex AI models may provide limited explanations for why a particular design was produced. These limitations make independent simulation, structural verification, and professional review essential. Wu et al. (2023) emphasize the importance of evaluating generative AI outputs carefully, while Wang et al. (2024) discuss the broader capabilities and limitations associated with the development of generative models. These concerns are especially important in structural engineering, where design errors can have serious safety consequences.The growing integration of artificial intelligence into engineering workflows creates a need to examine both its capabilities and its practical limitations. Generative AI should not be considered an independent substitute for structural analysis, design standards, or qualified engineering judgment. Instead, it can function as a supporting technology that produces candidate solutions for evaluation through established engineering procedures. Effective implementation requires reliable training data, clearly defined design constraints, simulation-based validation, and compliance with applicable structural codes. This study therefore examines how generative artificial intelligence can support automated design of engineering structures, with particular attention to design exploration, structural performance, material efficiency, and implementation challenges. Through a qualitative review of existing literature, the study aims to provide an integrated understanding of the opportunities and responsibilities associated with AI-assisted structural design.

RESEARCH OBJECTIVES

1. To examine the role of generative artificial intelligence in automating the design of engineering structures.
2. To evaluate the potential of generative AI to improve structural design efficiency, performance, and material utilization.
3. To identify the technical, safety, and implementation challenges associated with generative AI-based structural design.

RESEARCH QUESTIONS

1. How can generative artificial intelligence support the automated design of engineering structures?
2. To what extent can generative AI improve structural design efficiency, performance, and material utilization?
3. What technical, safety, and implementation challenges affect the use of generative AI in structural engineering?

INTERNATIONAL JOURNAL OF APPLIED AI IN ENGINEERING SCIENCES

Vol.01-01-2026 E ISSN:XXXX-XXXX P ISSN:XXXX-XXXX

LITERATURE REVIEW

Research on artificial intelligence-aided design has expanded as engineers seek methods for addressing the complexity, time requirements, and multiple constraints associated with structural development. Ao et al. (2025) reviewed AI-aided design across marine, aerospace, automotive, civil, and composite structures, identifying opportunities to improve design exploration and reduce repetitive work. Their review suggests that AI can help engineers address high-dimensional design problems involving several competing objectives. However, the reliability of generated solutions, data requirements, and industry acceptance remain important concerns. This research provides a broad foundation for examining generative AI as a supporting technology in automated structural design.Liao et al. (2024) specifically examined generative AI for building structures, discussing data representation, generation algorithms, evaluation methods, and the integration of generative models with optimization techniques. Their review highlights the importance of designing models that can learn from existing structural information and generate alternatives that respond to architectural and engineering requirements. Generative AI can expand the range of candidate designs considered during early development, but those alternatives must be assessed for physical feasibility and structural performance. This research demonstrates the value of combining generative capabilities with established engineering evaluation methods.

Kookalani et al. (2024) reviewed the progression of building and structural design automation, from conventional generative design to deep generative models and optimization. Their study considers methods such as generative adversarial networks, variational autoencoders, and reinforcement learning, alongside topology optimization. The review indicates that integrating deep generative models with optimization can support the production of a broader range of structural alternatives. It also emphasizes the need for further development in the creation of innovative designs and the practical integration of automated systems. These findings are relevant to engineering structures in which geometry, material use, and performance must be considered together.The development of integrated structural design workflows is another important area of research. He et al. (2025) introduced Generative AIBIM, a structural design pipeline integrating building information modelling (BIM) with generative AI. Their approach uses a generation framework that incorporates physical conditions, demonstrating how AI-based generation can be connected with structured engineering information. Such integration can help link design concepts with more detailed structural models and improve coordination between different design stages. Nevertheless, the quality of generated designs depends on accurate input information, appropriate physical constraints, and reliable evaluation procedures. This research supports the view that generative AI is most useful when integrated into a wider engineering workflow rather than used as an isolated design tool.

INTERNATIONAL JOURNAL OF APPLIED AI IN ENGINEERING SCIENCES

Vol.01-01-2026 E ISSN:XXXX-XXXX P ISSN:XXXX-XXXX

Zhang et al. (2024) investigated end-to-end generation of structural topologies for complex architectural layouts using graph neural networks and a generative adversarial network. Their research addresses limitations in automated structural topology design by using architectural layouts to guide the generation of structural nodes and connections. The study reports promising results for generating structural topologies that correspond to complex layouts, illustrating the potential of generative models to support practical design tasks. This work is particularly relevant to buildings and other structures where the arrangement of structural elements must correspond to architectural constraints. However, generated topologies still require engineering assessment to determine whether they satisfy loads, stability, constructability, and applicable design standardsGao et al. (2024) examined structural topology optimization using diffusion generative adversarial networks. Their method aims to improve generation quality and computational efficiency by combining diffusion processes with a generative adversarial framework. This research illustrates how advanced generative methods can contribute to structural optimization by exploring alternative material distributions and structural configurations. The results suggest opportunities for improving automated design processes, although practical applications require careful consideration of model performance and computational demands. The study also demonstrates the importance of evaluating generated structures using engineering-specific measures rather than judging designs only by their geometric appearance.Naser et al. (2025) reviewed generative artificial intelligence in civil and environmental engineering, identifying applications that include automated structural layouts and other design-related tasks. Their review highlights continuing barriers such as limited domain-specific data, inconsistent datasets, integration with existing engineering workflows, the need for systematic evaluation metrics, and compliance with engineering codes. These issues are central to the use of generative AI in structural design because the generation of an attractive or novel concept does not establish that it is safe or suitable for construction. Taken together, the literature indicates that generative AI offers considerable potential for structural design automation, but its successful application depends on integrating data-driven generation with simulation, validation, professional judgment, and regulatory requirements.

METHODOLOGY

This study adopts a qualitative, literature-based methodology to examine the application of generative artificial intelligence in automated engineering structure design. The study draws on published scholarly research identified through academic search resources, including Google Scholar, and focuses on studies concerning generative design, structural topology generation, deep generative models, building information modelling, and AI-assisted engineering design. Relevant literature was examined to identify major model types, engineering applications, reported benefits, and implementation limitations. The selected research includes review articles and technical studies published between 2024 and 2025, providing a basis for understanding recent developments in the field.

INTERNATIONAL JOURNAL OF APPLIED AI IN ENGINEERING SCIENCES

Vol.01-01-2026 E ISSN:XXXX-XXXX P ISSN:XXXX-XXXX

The analysis focuses on the ways generative AI can contribute to structural design exploration, workflow automation, structural optimization, and material efficiency. It also considers the limitations identified by researchers, including data availability, physical feasibility, computational demands, model reliability, and compliance with engineering standards. Rather than conducting new structural experiments or collecting primary data, the study synthesizes existing findings to develop an overall understanding of the opportunities and risks associated with generative AI. This approach is suitable for identifying current research trends and highlighting areas that require further engineering validation.

RESEARCH DESIGN

The study uses a descriptive and analytical research design based on a narrative review of scholarly literature. The descriptive component identifies the main generative AI methods used in structural design, including generative adversarial networks, variational autoencoders, diffusion models, and graph-based generative techniques. The analytical component compares their applications in building structures, structural topology generation, and computational optimization. This design makes it possible to examine how different approaches support automated generation and how they can be integrated with existing engineering tools (Ao et al., 2025; Kookalani et al., 2024).The research design also considers the relationship between design automation and engineering reliability. Potential benefits, including wider design exploration, reduced repetitive modelling, and improved material distribution, are assessed alongside challenges involving structural safety, data quality, physical feasibility, and regulatory compliance. The study does not involve primary experiments or new structural simulations; therefore, its findings represent a qualitative synthesis of existing research rather than independent measurements of performance or cost savings. This distinction is important when interpreting the practical value of generative AI in engineering applications.

DATA ANALYSIS

The literature was analyzed thematically to identify the principal applications of generative AI in automated structural design. Four major themes emerged: automated generation of structural configurations, integration with engineering software, topology optimization, and evaluation of structural feasibility. Research by Liao et al. (2024) and Zhang et al. (2024) illustrates how generative methods can produce structural alternatives based on architectural layouts and design information. Meanwhile, He et al. (2025) demonstrate the potential of integrating generative AI with building information modelling to support a more connected structural design workflow.A further stage of analysis focused on the challenges that influence the reliability of AI-generated structures. These include limited or inconsistent training data, computational complexity, physical constraints, model interpretability, and compliance with engineering codes. Gao et al. (2024) examine computational methods for improving structural topology generation, while

INTERNATIONAL JOURNAL OF APPLIED AI IN ENGINEERING SCIENCES

Vol.01-01-2026 E ISSN:XXXX-XXXX P ISSN:XXXX-XXXX

Naser et al. (2025) highlight wider barriers to adopting generative AI in civil and environmental engineering. The comparison suggests that design quality must be evaluated through engineering-specific criteria, including strength, stability, serviceability, constructability, and material efficiency. Because the study uses existing literature, no new statistical calculations or experimental performance measurements were conducted.

FINDINGS

The findings indicate that generative AI can support automated structural design by producing multiple candidate configurations and expanding the range of alternatives available to engineers. Generative adversarial networks, diffusion models, and graph-based methods can help explore structural geometries, topologies, and element arrangements that may be difficult to develop through conventional manual processes alone. Studies by Zhang et al. (2024) and Gao et al. (2024) demonstrate the potential of generative techniques for structural topology generation and optimization. These capabilities can assist engineers during early-stage design and provide additional alternatives for subsequent analysis.A second finding is that integrating generative AI with established engineering tools can improve the continuity of the design process. Linking generative models with building information modelling, structural simulation, and optimization tools can help connect initial concepts with detailed engineering evaluation. He et al. (2025) demonstrate the relevance of integrating generative AI with BIM, while Liao et al. (2024) discuss the combination of generative design and optimization. These approaches may reduce repetitive tasks and support more systematic design exploration. However, the actual improvements in design time, cost, or material efficiency depend on the specific system and must be evaluated through appropriate testing.The third finding concerns the importance of safety, validation, and professional oversight. Generative AI can produce designs that appear plausible but may not satisfy loading conditions, structural stability requirements, construction limitations, or applicable codes. Data limitations, computational requirements, and integration difficulties may further restrict implementation. Ao et al. (2025) and Naser et al. (2025) identify important challenges involving reliability, data availability, and industry adoption. Consequently, generative AI should be used as a supporting design technology, with generated alternatives subjected to independent engineering analysis and professional review before practical implementation.

CONCLUSION

Generative artificial intelligence offers promising opportunities for automating the design of engineering structures by generating alternative configurations, supporting topology optimization, and improving the exploration of complex design spaces. Its integration with building information modelling, computational simulation, and engineering optimization can help streamline design workflows and support innovative structural solutions. The literature

Vol.01-01-2026 E ISSN:XXXX-XXXX P ISSN:XXXX-XXXX

reviewed in this study indicates that generative AI has potential applications in building structures, bridges, lightweight components, and other engineering systems where multiple design requirements must be considered simultaneously.However, the successful application of generative AI requires more than the ability to produce new designs. Structural safety, physical feasibility, data quality, material performance, constructability, and regulatory compliance must remain central to the design process. Future research should prioritize reliable training datasets, physics-informed generation, standardized evaluation methods, and integration with established engineering software. In conclusion, generative AI can become a valuable tool for automated structural design when combined with rigorous engineering validation, appropriate technical constraints, and qualified professional judgment.

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