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GENERATIVE AI ADOPTION IN CIVIL ENGINEERING: A MINI REVIEW OF BENEFITS, BARRIERS, AND RISKS

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Abstract

Generative Artificial Intelligence (GenAI) is emerging as a transformative technology in civil engineering, offering new capabilities in design automation, project management, and real-time decision-making. This review aims to systematically examine the key benefits, barriers, and risks associated with GenAI adoption in the civil engineering domain. To do so, we employed the PRISMA methodology to conduct an in-depth analysis of twenty-two peer-reviewed documents retrieved from Google Scholar. The findings reveal ten key benefits, with design optimization and creativity, progress monitoring and reporting, and improved risk management standing out as the most prominent. In addition, thirteen critical barriers were identified, notably privacy and data ownership concerns, software integration challenges, and high upfront investment costs. Furthermore, ten distinct risks were outlined, including overreliance on AI, copyright issues, and bias in training data, which are the most severe risks. Finally, this study proposes eight promising research directions for future exploration, ranging from human-AI collaboration models to legal and ethical frameworks, data interoperability, and AI trust mechanisms, all of which are vital to supporting the safe and effective integration of GenAI in civil engineering practices.

Keywords: artificial intelligence; building, structure & design; construction; risk assessment.

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1. Introduction

The civil engineering sector is undergoing a profound transformation driven by digital technologies, among which Generative Artificial Intelligence (GenAI) is emerging as a powerful force for innovation [1, 2]. GenAI refers to AI systems capable of generating content, such as text, design models, construction plans, and simulations, based on training data and user input [3]. In civil engineering, the adoption of GenAI offers the potential to revolutionize traditional workflows by enabling faster design iterations, enhancing creativity, supporting risk assessment, and optimizing project management processes [3–5]. With increasing pressure to deliver infrastructure more efficiently, sustainably, and cost-effectively, GenAI presents a strategic opportunity to enhance productivity, reduce errors, and improve decision-making across the project lifecycle [6]. Its integration aligns with broader industry trends toward automation, digital twins, and smart infrastructure, signaling a paradigm shift in how engineers conceptualize, design, and execute projects.

Despite the growing interest in GenAI, the practical adoption of these technologies in civil engineering remains uneven and fraught with uncertainty. While numerous academic and industry publications have begun exploring individual aspects of GenAI, such as its design capabilities [4], integration with BIM [7], or ethical implications [8], there is a lack of comprehensive synthesis that addresses its multidimensional impact. This review aims to fill that gap by systematically examining the current literature to identify and assess the key benefits, barriers, and risks associated with

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GenAI adoption in civil engineering. By mapping out the opportunities and limitations of GenAI through thematic analysis of selected sources, this paper seeks to inform both scholarly discourse and practical decision-making. The objectives are threefold: (1) to evaluate the range and frequency of documented benefits, (2) to uncover critical technical, organizational, and ethical barriers, and (3) to highlight emerging risks that may influence the responsible implementation of GenAI in engineering contexts. Through this effort, this review contributes to a clearer understanding of the state-of-the-art and provides strategic insights for future research, policy, and practice.

This review is structured into five main sections to provide a comprehensive understanding of GenAI adoption in civil engineering. Section 1 presents the Introduction, highlighting the significance of GenAI and the rationale for this review. Section 2 outlines the Materials and Methods, detailing the application of the PRISMA framework for identifying and analyzing relevant literature. Section 3 delivers the Results and Discussion, divided into three subsections: 3.1 discusses the key benefits of GenAI adoption, 3.2 examines the primary barriers hindering implementation, and 3.3 explores the potential risks associated with its use. Section 4 proposes Future Research Directions, suggesting promising research areas for further investigation based on the review findings. Finally, Section 5 presents the Conclusion and Limitations, summarizing the study's key contributions while acknowledging its scope constraints.

2. Materials and methods

This literature review adopted the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework [9, 10] to ensure a structured, transparent, and reproducible approach to literature selection and analysis. In this study, PRISMA was applied as a guiding framework for structuring the literature review process rather than for strict quantitative reporting. The literature search and data collection were conducted between January 5, 2025 and April 10, 2025, ensuring the inclusion of the most up-to-date studies in the rapidly evolving field of GenAI. The methodology consisted of four key phases as outlined by PRISMA: identification, screening, eligibility, and inclusion, each designed to systematically refine the body of literature to the most pertinent studies addressing the benefits, barriers, and risks of GenAI adoption in civil engineering.

The initial identification phase focused on sourcing relevant academic literature primarily through the Google Scholar database. This platform was selected due to its extensive coverage of journals, conference proceedings, and other scholarly publications across a wide array of disciplines, including engineering and computer science [11]. This breadth makes Google Scholar particularly suitable for capturing emerging and cross-disciplinary research on GenAI. The search strategy employed a carefully constructed query using specific keywords combined with Boolean operators to maximize the retrieval of relevant documents. The comprehensive search string was: ("benefits" OR "enablers" OR "drivers" OR "barriers" OR "challenges" OR "opportunities" OR "risks") AND ("GenAI" AND "Large language model" OR "Chat GPT" OR "Google bard" OR "Gemini" OR "generative artificial intelligence") AND ("civil engineering" OR "design" OR "construction"). Although numerous GenAI and large language model–based systems currently exist, this review focused on ChatGPT, Bard, and Gemini because they represent the most mature, widely adopted, and well-documented general-purpose GenAI tools during the review period. Importantly, these tools were used as representative examples of GenAI in the civil engineering literature, and the study does not exclude other models conceptually. Many of the reviewed studies discuss GenAI at a functional or conceptual level rather than through model-specific implementations.

Following the identification of records, a multi-stage screening process was implemented. First, publication filters were applied to restrict the search results to articles published in the English language between January 2022 and April 2025. This timeframe was chosen to capture the most recent advancements and discussions surrounding the rapidly evolving field of GenAI. Subsequently, the retrieved records were screened based on document type. Non-research formats, including editorials, book reviews, letters to the editor, discussions, introductions to special issues, and briefing sheets, were excluded to ensure that only substantive research contributions were considered. This screening process yielded an initial set of documents for further assessment.

The eligibility of the documents that passed the screening phase was then assessed through a detailed review. Titles and abstracts of these documents were meticulously examined to determine their direct relevance to the core themes of the review: specifically, the benefits, barriers, risks, enablers, opportunities, or challenges associated with the adoption and implementation of GenAI (including specific tools like ChatGPT, Bard, and Gemini, or broader concepts like Large Language Models) within the civil engineering, design, or construction domains. Articles that did not clearly address these intersections were excluded at this stage.

Finally, the inclusion phase aimed to ensure comprehensive coverage of the relevant literature. This involved a supplemental search strategy wherein the reference lists of the documents deemed eligible from the previous phase were scrutinized for any additional pertinent studies that may have been missed in the initial database search (a technique often referred to as backward citation searching or snowballing). Through this iterative process of identification, screening, eligibility assessment, and supplemental reference list searching, a final corpus of twenty-two related documents was identified and included in this review for detailed analysis and synthesis.

3. Results and discussion

3.1. Key benefits of GenAI adoption in civil engineering

This review presents findings from an in-depth analysis of fourteen documents pertaining to the benefits of GenAI adoption in the civil engineering sector. Ten key benefits were identified from this literature, as shown in Table 1. To establish a hierarchy of importance, each benefit was ranked based on the number of documents in which it was identified. This frequency of mention serves as a proxy for the benefit's perceived significance within the reviewed scholarship. According to this ranking, presented in Table 1, the three most prominent benefits are: design optimization and creativity (identified in 8 documents), followed by enhanced progress monitoring and reporting, and improved risk management (each identified in 7 documents).

The most frequently cited benefit, appearing in eight documents, is the capacity of GenAI for design optimization and creativity. This involves leveraging AI to produce AI-Generated Designs, thereby enhancing creativity and accelerating ideation in the early stages of a project [2, 5, 7]. Studies highlight AI's ability to achieve design optimization, leading to optimal design and construction techniques and enhanced structural performance [1, 5, 6, 12, 18]. This can extend to material selection and optimization, contributing to overall innovation in civil engineering solutions, including considerations for energy efficiency and sustainable materials [1, 6, 12, 18]. Furthermore, GenAI supports broader project planning and design, can improve existing BIM workflows, and allows engineers to explore a wider range of possibilities more efficiently, including the generation of design concepts [12, 15, 18].

Following closely, with mentions in seven documents, is the benefit of enhanced progress monitoring and reporting. GenAI can significantly improve how civil engineering projects are tracked, offering capabilities for real-time project management and automated tracking [1]. This allows for continuous progress tracking and the generation of essential documentation such as project management plans, status reports, communication facilitation, and post-project reviews [1, 3, 19]. Such

Table 1. Key benefits of GenAI adoption in civil engineering

Key benefits identified	[1]	[2]	[12]	[7]	[13]	[3]	[14]	[5]	[15]	[16]	[17]	[18]	[19]	[6]	Total
Enhanced planning and scheduling	x		x			x						x	x	x	6
Improved safety planning	x				x	x		x				x	x		6
Resource optimization			x			x		x	x			x		x	6
Enhanced progress monitoring and reporting	x				x	x			x	x		x	x		7
Design optimization and creativity	x	x	x			x		x		x		x		x	8
Cost reduction			x									x		x	3
Better communication and visualization	x											x			2
Sustainability and Performance			x		x							x		x	4
Improved risk management		x	x	x		x		x				x		x	7
Enhanced decision-making		x										x		x	3

enhancements lead to improved communication and situational awareness among project stakeholders and contribute to enhanced project coordination [1, 13]. The data gathered through real-time monitoring can also feed into data analysis and performance enhancement and schedule prediction and optimization, providing a clearer view of project status, facilitating timely interventions, and even aiding in site safety management through diligent oversight [1, 13, 19]

Equally prominent, also identified in seven documents, is improved risk management. GenAI offers powerful tools for proactively addressing potential hazards in civil engineering projects. Studies indicate it enables early risk identification and mitigation and can assist with the comprehensive process of identifying, assessing, and mitigating risks, as well as the creation of risk reports and risk response strategies [3, 7]. This includes conducting risk analysis and leveraging predictive analytics for safety risk assessment and prediction [13, 19]. The ultimate aim is effective risk mitigation, a reduction in operational risks, and assistance with contingency planning [1, 3, 5]. This leads to enhanced safety protocols, better site safety management, and an overall increase in safety awareness throughout the project lifecycle [1, 18].

3.2. Key barriers to adopt GenAI in civil engineering

An in-depth analysis of fourteen selected documents was conducted to identify barriers to GenAI adoption in civil engineering. This yielded thirteen distinct key barriers, presented in Table 2. The relative significance of these barriers was determined by their frequency of mention across the seventeen documents, with a higher count indicating greater perceived impact. Accordingly, Table 2 highlights the most prominent barriers: (1) Privacy, intellectual property, and data ownership concerns (cited in 8 documents); (2) integration challenges with existing software and BIM systems (cited in 8 documents); and (3) high upfront investment in technology and training (cited in 7 documents).

A primary obstacle to the adoption of GenAI in civil engineering, cited in eight documents, encompasses privacy, intellectual property, and data ownership concerns. The use of GenAI often involves processing vast amounts of data, which can include sensitive project details, proprietary designs, and in-house cost data, leading to concerns about confidentiality and potential loss of competitive advantage [8, 15]. There are significant privacy and data protection challenges associated with how this information is stored, handled, and used by AI models [21]. Furthermore, ethical issues arise concerning intellectual property, particularly in presenting AI-generated work as one's own or

Table 2. Key barriers to adopt GenAI in civil engineering

Key barriers identified	[1]	[2]	[8]	[6]	[20]	[21]	[22]	[23]	[15]	[24]	[4]	[18]	[25]	[7]	Total
Lack of high-quality, structured, and domain-specific data				x			x				x	x	x	x	6
Data fragmentation across stakeholders and lifecycle phases				x								x	x	x	4
Privacy, intellectual property, and data ownership concerns		x	x			x	x	x	x			x	x		8
Ambiguity in liability and accountability for AI-generated outputs		x	x			x						x	x		5
Integration challenges with existing software and BIM systems	x	x		x		x			x			x	x	x	8
Limited real-time or on-site application capabilities				x		x			x			x	x		5
High computational demands (cloud, edge requirements)				x		x						x	x		4
Resistance to change and low digital maturity in many firms	x			x		x	x					x	x		6
Skill gaps in AI, machine learning, and data science among workforce	x			x		x	x					x			5
Lack of training or understanding of AI capabilities		x		x		x	x					x			5
High upfront investment in technology and training	x	x		x		x	x					x	x		7
Uncertainty around return on investment		x		x		x	x					x	x		6
Lack of standardization or regulations		x		x		x				x	x	x			6

determining authorship when designs are co-created with AI, which also touches upon the need for robust cybersecurity measures to protect these valuable assets [8, 18].

Equally prominent, and also mentioned in eight documents, are the integration challenges with existing software and BIM systems. The civil engineering sector heavily relies on established software ecosystems, including Building Information Modeling (BIM) platforms, and ensuring seamless interoperability with new GenAI tools is a significant hurdle [6, 15, 18]. The complexity in tool integration can disrupt existing workflows and lead to inefficiencies if data cannot be easily exchanged or if AI outputs are not compatible with current design and project management tools [1, 6, 7]. This challenge extends to the need for cross-platform validation and ensuring that GenAI can effectively communicate with diverse existing systems without causing errors or requiring extensive manual adjustments [7, 8].

The third major barrier, identified in seven documents, is the high upfront investment in technology and training. Implementing GenAI solutions involves considerable financial outlay for the technology itself, as well as for the necessary infrastructure and potential software licenses, making affordability a key factor [1, 8, 18]. Beyond the initial capital for technology, there are substantial costs associated with implementation, including the need for workforce training to develop the skills required to operate, manage, and validate AI-generated outputs [1, 18, 22]. This requirement for new technical expertise, coupled with a potential lack of skilled workers and an uncertain return on investment, makes the high cost of adoption a significant deterrent for many firms in the sector [18, 22].

3.3. Risks of GenAI adoption in civil engineering

To understand the potential risks of GenAI adoption in civil engineering, eight relevant documents underwent in-depth analysis. This identified ten distinct risks, as detailed in Table 3. These risks were subsequently ranked by their frequency of citation within the reviewed literature, serving as an indicator of their perceived severity. Table 3 reveals that the most frequently cited risks, appearing in three documents, are: (1) overreliance on AI without human validation or expert review; (2) copyright and authorship issues; and (3) biases embedded in training data leading to unfair outcomes.

Table 3. Risks of GenAI adoption in civil engineering

Main risks identified	[21]	[2]	[25]	[8]	[22]	[23]	[6]	Total
Hallucination or generation of incorrect or unsafe outputs		x					x	2
Overreliance on AI without human validation or expert review		x	x				x	3
Copyright and authorship issues	x			x		x		3
Biases embedded in training data leading to unfair outcomes	x			x		x		3
Potential reduction in demand for certain roles (e.g., draftsmen, estimators)	x							1
Workforce anxiety or resistance due to fear of replacement	x							1
Increased risk of cyberattacks due to cloud-based AI systems							x	1
Potential exposure of sensitive project data				x			x	2
Black-box nature of AI models limiting explainability				x	x			2
Difficult to audit AI-generated decisions or outputs				x				1

One of the most frequently cited risks in literature is the overreliance on AI-generated outputs without adequate human oversight or expert validation. This concern stems from the inherent limitations of current GenAI, such as its potential for hallucinations or generating inaccurate content [2, 6]. Previous studies emphasize the critical need for accuracy and generalizability in AI models, and the necessity of verifying generated content and validating novel ideas in real-world scenarios [2, 6]. Without human oversight, especially from professionals with deep domain knowledge, civil engineering projects could face significant operational risks, including potential safety issues if flawed AI outputs are directly implemented [2, 22, 24, 25]. The integrity of data fed into and produced by AI is paramount [8]. A lack of human review can lead to the unquestioned adoption of erroneous or suboptimal solutions, underscoring the need for continuous model updates and interpretability, and robust risk management procedures [2, 13].

Another highly cited risk involves copyright and authorship issues associated with AI-generated content. This touches upon fundamental ethical and legal risks concerning intellectual property [25]. Specifically, there are ethical issues in presenting GenAI-generated work as one's own, which can be problematic in a field where accountability for designs and reports is crucial [8]. The challenge of AI detection and the difficulty in ensuring individuals or teams indicate the use of AI further complicate the attribution of work [22]. In civil engineering, where designs, plans, and specifications carry legal weight, ambiguity over authorship or the unacknowledged use of AI-generated elements could lead to disputes over ownership, liability, and professional responsibility, falling under broader ethical challenges [2].

Finally, the risk of biases embedded in training data leading to unfair or inequitable outcomes was also cited as a major concern. GenAI models learn from vast datasets, and if these datasets reflect historical or societal biases, the AI can perpetuate or even amplify them. This poses significant ethical challenges and can compromise the trust placed in AI systems [2, 22]. Such biases can affect the generalizability of AI solutions, potentially leading to designs or decisions that disadvantage certain communities or overlook specific needs, thereby contributing to increased socio-economic inequality [2, 21]. For civil engineering projects, which often have profound societal impacts, biased AI could lead to inequitable infrastructure development, resource allocation, or risk assessment, undermining the goal of serving all members of society fairly.

4. Future research directions

Despite the emerging body of literature on GenAI in civil engineering, several research directions remain underexplored and warrant further investigation.

One critical area is enhancing human-AI collaboration in engineering workflows. Prior studies [1, 3, 5, 7, 15] have demonstrated that GenAI can support a broad range of tasks including project planning, safety monitoring, and design optimization. However, future research is needed to determine how GenAI can complement rather than replace human decision-making. Questions remain on the optimal models of collaboration between engineers and AI systems, how GenAI can provide adaptive, context-aware support, and how to preserve creativity and engineering judgment in hybrid workflows.

A second major research priority concerns trust, transparency, and verification of GenAI outputs. Several studies [2, 6, 8, 18, 21] highlight the risks of hallucination, inaccurate predictions, and unverifiable content. Future research should explore effective verification protocols to assess GenAI-generated results in design, planning, and analysis. This includes developing traceability mechanisms, confidence scoring systems, and tools for validating AI logic. Additionally, user-centered transparency strategies are needed to enhance engineers' trust and ability to critically assess AI recommendations.

The third area of interest involves the legal, regulatory, and ethical governance of GenAI in civil engineering practice. Studies [18, 21, 24, 25] point to gaps in existing legal frameworks and ethical standards, particularly in regard to intellectual property, accountability, and compliance. Future investigations could explore how emerging regulatory frameworks can adapt to AI-enabled decision-making in infrastructure projects. Research is also needed on the development of ethical guidelines for attributing GenAI-generated content and ensuring that liability for decisions remains clear and fair across stakeholders.

Organizational and workforce-related barriers present another important avenue for research. While the benefits of GenAI are clear, studies [1, 8, 18, 22, 25] show persistent challenges including resistance to change, lack of skilled personnel, and the high cost of implementation. There is a need to explore effective training models and organizational strategies to facilitate adoption. Questions include how to design professional development programs for GenAI tools, what incentives can encourage adoption in SMEs, and how leadership styles and company culture influence the acceptance of new technologies.

Another significant research direction relates to interoperability and integration. Technical challenges such as limited tool compatibility, data exchange constraints, and software interoperability are reported in multiple studies [6, 7, 15]. Future studies should investigate methods for integrating GenAI with existing digital platforms such as BIM, GIS, and scheduling tools (e.g., Primavera P6).

In particular, research is needed on developing data standards, middleware solutions, and platform-neutral APIs that support cross-system compatibility while ensuring data integrity and security.

Sustainability is a growing concern in construction, and GenAI offers new opportunities in this area. Studies [2, 5, 12, 13] emphasize GenAI's potential in sustainable infrastructure design, energy modeling, and material efficiency. Further research is needed to examine how GenAI can support low-carbon design generation, optimize life cycle performance, and assist in smart material selection. In addition, investigations into how GenAI simulations and decision-support systems contribute to achieving green certifications and resilience targets are essential.

The issue of prompt engineering and user interface design is also crucial. According to [6, 7, 15], engineers face difficulties in formulating effective prompts and interacting with GenAI tools. This suggests a need for research on the development of intuitive interfaces, AI-assisted prompt formulation tools, and domain-specific interaction models that enhance user productivity. Investigating how GenAI systems can adapt to the varying needs and expertise levels of different users is also critical.

Finally, a longitudinal evaluation of GenAI's impact on project outcomes is required. While short-term benefits such as productivity gains and decision support are well-documented [1, 3, 5], empirical evidence on long-term impacts remains limited. Future research should focus on tracking project outcomes, such as cost, schedule, quality, safety, and stakeholder satisfaction, over time to assess the sustained value of GenAI. Additionally, attention should be given to potential unintended consequences, including over-reliance on AI tools or skill degradation among practitioners.

5. Conclusions and limitations

This study provided a synthesis of the current landscape of GenAI adoption in civil engineering, highlighting its transformative potential alongside critical implementation challenges. This literature review adopted the PRISMA methodology, following its four key phases, identification, screening, eligibility, and inclusion, to conduct an in-depth analysis of twenty-two relevant documents. The review identified ten key benefits of GenAI adoption, with the most prominent being enhanced design optimization and creativity, improved progress monitoring and reporting, and strengthened risk management capabilities. Thirteen distinct barriers were also revealed, including concerns over privacy, intellectual property, and data ownership; integration difficulties with existing software and BIM platforms; and the substantial initial investment required for technology acquisition and workforce training. Additionally, the review identified ten critical risks, with the most severe being overreliance on AI systems without sufficient human validation, unresolved copyright and authorship issues, and algorithmic biases in training data that may lead to inequitable or flawed outcomes. Furthermore, this study proposes eight promising research directions for future exploration, ranging from human-AI collaboration models to legal and ethical frameworks, data interoperability, and AI trust mechanisms, all of which are vital to supporting the safe and effective integration of GenAI in civil engineering practices.

Despite offering valuable insights, this review has several limitations that should be acknowledged. Firstly, this study relied solely on the Google Scholar database for literature retrieval, which, while comprehensive, may have excluded relevant studies indexed in other academic databases such as Scopus, Web of Science, or IEEE Xplore. Secondly, this review was limited to an analysis of only twenty-two documents, which may not fully capture the breadth of emerging research or the rapidly evolving applications of GenAI in civil engineering. Lastly, the scope of the review was narrowly focused on identifying benefits, barriers, and risks, excluding other important dimensions such as implementation strategies, regulatory developments, user perceptions, and long-term impacts. These limitations suggest that future reviews could benefit from broader database inclusion, larger sample sizes, and a more expansive thematic focus.

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