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Opinion

Artificial Intelligence Integration in Structural Design and Analysis for Civil Engineering Applications

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Introduction

Since the initial exploration of artificial intelligence (AI) applications in structural and design engineering, significant research has emerged in this field. AI, a branch of science enabling software to solve complex problems akin to human cognition, has played a transformative role in various industries. However, the construction industry, being one of the oldest sectors, has faced persistent challenges such as budget overruns, project delays, and overall inefficiency. While advancements in construction technology have been made, the fundamental approach to project design and management has seen limited evolution. Unlike industries like automotive and manufacturing, which have adapted modern methodologies to enhance productivity, construction practices have remained relatively unchanged. AI, prevalent for decades, has demonstrated its effectiveness in improving efficiency and performance in various industries. In civil engineering and construction, AI applications have traditionally focused on project management and post-construction stages. However, recent research indicates the potential for AI integration in the design phase, particularly in structural element design. This article explores the utilization of AI in designing structural elements of buildings, with a focus on achieving optimal designs efficiently.

Optimizing Design with AI

Historically, designers often opted for suboptimal designs due to the time-intensive nature of iterating and optimizing large-scale structures. Generic software limitations and slow simulation times further contributed to this challenge. AI addresses this issue by significantly reducing simulation and analysis times, as evidenced by previous studies. AI has proven accurate in delivering optimized design solutions, emphasizing stability and reduced overall mass. While recent studies primarily concentrated on optimizing cross-sections of columns and beams concerning their masses, this article broadens the scope to include various structural elements such as beams, columns, slabs, and walls in relation to their cross-sectional areas and masses. The focus is on leveraging AI for fast and accurate simulations, presenting optimized results for design solutions through AI-backed Neural Networks. The article also reviews AI methodologies, discusses related literature, and explores potential avenues for future research in AI within civil engineering.

AI in the Construction Industry

Since AI's introduction to the construction industry, it has significantly enhanced performance, efficiency, and overall project output. AI has revolutionized damage detection, structural health monitoring, and post-construction maintenance. Defined as a segment of computer science, AI empowers the development of software and machines with intelligence comparable to human capabilities. AI excels in solving complex problems and navigating uncertainties, offering a superior alternative to traditional problem-solving methods. Issues in construction projects are diverse, requiring specialized expertise for resolution. AI proves invaluable by adapting to specific project requirements and exceeding human problem-solving capacities. The terms Artificial Intelligence (AI) and Machine Intelligence (MI) are often used interchangeably, with MI referring to machines emulating human behavior and intelligence, while AI focuses on machines mimicking human tasks more efficiently.

Applications of AI in Civil Engineering

Recent studies emphasize the integration of AI subcategories, such as Machine Learning (ML), with structural design and analysis for further optimization. Achieving a fundamentally sound and economically viable structure is considered an optimized solution. AI applications like Pattern Recognition (PR), Fuzzy Logic, and Artificial Neural Networks (ANN) have gained prominence in different aspects of construction. The integration of PR and ML in structural engineering has been particularly effective in damage detection (DT) and structural health monitoring (SHM). A hybrid AI system combining both PR and ML can facilitate immediate and simplified DT. Using sensors and cameras, structures can be continuously monitored, and algorithms, trained on data from similar structures, can categorize and detect issues promptly. ML further refines the analysis, providing actionable insights and solutions to mitigate identified issues. Recent research has explored the application of AI in the design phase, aiming to optimize the process. Finite Element Analysis (FEA) traditionally relies on software such as ETAB's, Robot Structural Analysis, and ANSYS. Designers conduct analyses on key load-bearing elements, with results interpolated for other columns, often leading to overdesigning and inefficient resource utilization. AI algorithms, specifically Neural Networks, offer a faster and more efficient alternative. Trained neural networks can analyze individual columns, providing optimized results in a shorter timeframe.

Discussion of Future Prospects

While existing literature primarily focuses on AI applications in post-construction phases, this article identifies prospects for utilizing AI in structural health monitoring systems and design analysis. Enhancing the serviceability and durability of structures in the post-construction phase involves engaging stakeholders effectively. Smart structures equipped with sensors can continuously monitor conditions and communicate wirelessly with developers, maintenance companies, and property owners. AI algorithms can promptly analyze sensor data, providing efficient solutions and proactive scheduling for upcoming services. Cloud computing ensures real-time communication, streamlining the process and saving time for all involved parties. AI's potential in design analysis can revolutionize the construction industry. Incorporating AI algorithms in the design phase, particularly in analyzing individual structural elements, can reduce overdesigning and provide optimized results efficiently. This shift from traditional FEA methods to AI-driven analyses holds promise for improving the overall efficiency and sustainability of construction projects.

Market Expansion

By 2026, the global AI in construction market is anticipated to achieve a valuation of $61 billion, demonstrating a robust compound annual growth rate of 31%. This underscores substantial potential and swift assimilation within the industry. According to a McKinsey report, AI has the potential to generate a value ranging from $1.2 trillion to $2.1 trillion in the architecture, engineering, and construction (AEC) sector by 2030. As per a 2022 Gartner report, it is predicted that 20% of structural engineers will incorporate AI-powered tools for design optimization by 2024. Research indicates that AI-driven structural analysis can attain accuracy rates surpassing 90% in specific scenarios. Studies focused on AI-induced design optimization showcase reductions in material usage of up to 30% while upholding structural integrity (Figure 1).

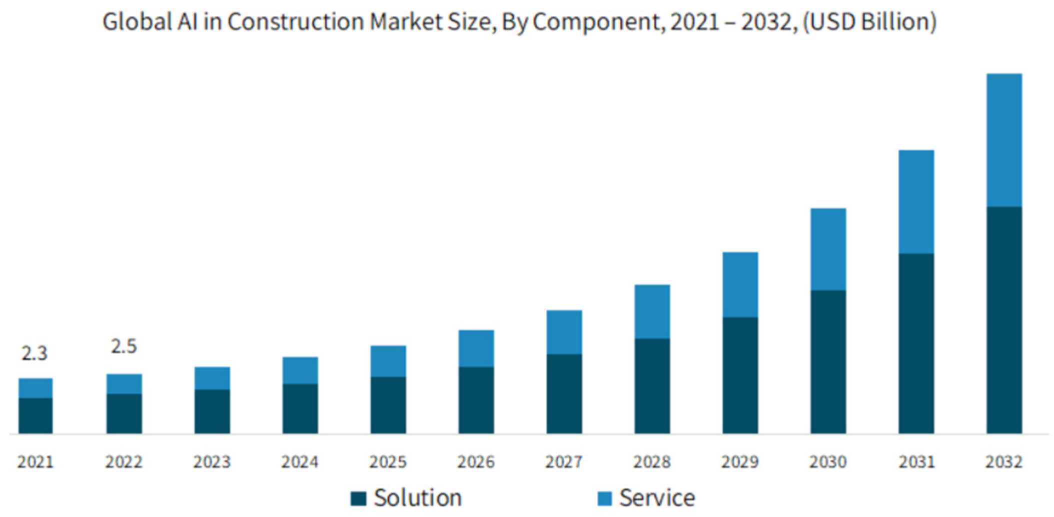

Figure 1: Source : GMI.

Obstacles and Constraints

Issues with data availability and quality pose challenges, as training AI models often necessitates substantial amounts of high-quality data, a resource that can be scarce in the construction industry. Transparency and explainability are additional concerns, with some AI models lacking clarity in their decision-making processes, thereby complicating the full comprehension and trust of their recommendations. Moreover, the ongoing evolution of standards and regulations related to AI application in structural design introduces uncertainty and obstacles to widespread adoption. In summary, while precise statistics may be elusive, the prevailing evidence strongly indicates that the integration of AI into structural design and analysis is an escalating trend, holding substantial promise for enhancing efficiency, precision, and sustainability in civil engineering endeavors.