

Structural Design Optimization and Cost Reduction Using Generative Artificial Intelligence Models

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Abstract—In recent years, the rise of generative artificial intelligence (AI) has opened up exciting new possibilities for the field of structural engineering. This technology is helping engineers create more efficient and cost-effective designs. In this paper, we explore how generative AI models can be applied to structural design, focusing on improving performance while also cutting costs. We present a carefully crafted framework that blends AI-generated design with traditional engineering analysis. This ensures that all designs meet safety standards and fulfill functional requirements.

Through a series of case studies on different structural systems, we demonstrate AI's impressive ability to innovate design configurations, use less material, and reduce construction expenses—all without compromising the strength and safety of the structures. Our findings show that generative AI has the potential to speed up the engineering design process, encourage creativity, and usher in a new era of sustainable and affordable building practices. This research marks an important step toward

making AI-driven optimization a regular part of structural engineering.

Keywords: Artificial Intelligence, Structural systems, Optimization.

I. INTRODUCTION

The rapid advancement of Artificial Intelligence (AI) has revolutionized multiple engineering sectors, and civil engineering is now experiencing a profound transformation through generative AI technologies. Structural design traditionally relies on analytical models, empirical codes, and iterative calculations that require significant time and manual effort. However, generative AI models—such as Generative Adversarial Networks (GANs), Variational Autoencoders (VAEs), and reinforcement learning algorithms—offer the ability to explore thousands of structural configurations within seconds, identify optimal solutions, and significantly reduce both material consumption and project costs.

This research paper focuses on how generative AI enhances structural design

optimization, improves engineering efficiency, enables material savings, and supports cost-effective construction practices while maintaining safety and code compliance.

II. BACKGROUND OF GENERATIVE AI IN CIVIL ENGINEERING

Generative AI refers to a class of machine learning models capable of producing new designs, patterns, or solutions based on learned data.

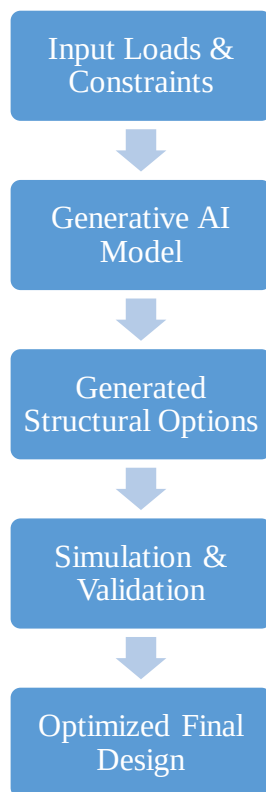


Figure 1 AI Driven Structural Design

In civil engineering, these models assist with:

- Generating optimized structural layouts
- Predicting load paths and stress distributions
- Automating reinforcement detailing
- Reducing trial-and-error in design iterations

With access to large datasets from building codes, BIM models, and structural simulations, AI systems can learn design logic and propose

efficient alternatives that traditional methods often miss.

A. Core Concepts of Structural Design Optimization

Structural optimization aims to create safe, economical, and efficient structures by analyzing load distribution, material strength, and geometry.

Key Objectives:

- Minimizing material usage
- Enhancing load-bearing performance
- Improving structural durability
- Lowering construction costs
- Optimization Methods Used:
 - Topology optimization: Removes unnecessary material.
 - Size optimization: Adjusts dimensions of beams, slabs, and columns.
 - Shape optimization: Modifies geometry for stress efficiency.

Generative AI enhances these methods by rapidly exploring non-intuitive solutions and evaluating thousands of configurations that manual engineering cannot practically achieve.

B. Generative AI Models for Structural Engineering Applications

Generative models play distinct roles based on their architecture:

Generative Adversarial Networks (GANs)

GANs generate multiple structural design variations and learn to refine them until they meet engineering constraints.

Variational Autoencoders (VAEs)

VAEs compress design information and generate optimized alternatives that balance strength and cost.

Reinforcement Learning (RL)

RL agents simulate structural loads and iteratively improve designs through reward-based learning.

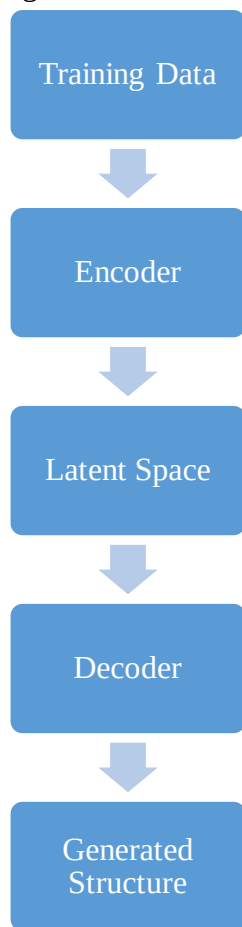


Figure 2 Workflow

C. Workflow of AI-Driven Structural Optimization

A typical AI-enabled optimization process includes:

- **Defining parameters:** Material grade, loads, safety factors, span lengths.
- **Inputting constraints:** Code requirements, serviceability limits, deflection criteria.
- **Running generative model:** AI proposes multiple optimized solutions.

- **Simulation and testing:** FEA or BIM-based simulation validates structural performance.
- **Selection of final design:** Optimal model chosen based on strength, cost, and sustainability.

D. Material Efficiency and Cost Reduction through AI Models

Generative AI helps reduce costs through:

Material optimization: Identifies redundant structural zones.

Smart reinforcement layouts: Reduces steel consumption.

Efficient cross-sectional designs: Minimizes concrete volume.

Automated design iteration: Cuts engineering man-hours by 30–50%.

Quantifiable Benefits (Approx.)

15–25% reduction in concrete volume

10–20% reduction in steel consumption

20–40% reduction in design time

AI removes material from low-stress zones

E. Case Study: AI-Based Optimization of a Reinforced Concrete Building Frame

Project Overview

A mid-rise commercial building (G+5) was selected for evaluating the efficiency of generative AI-based optimization techniques.

Inputs

Loads: IS 875 (Dead, Live, Wind)

Concrete Grade: M30

Steel Grade: Fe-500

Constraints: Serviceability, drift limits, column-slab connection guidelines

AI Model Used

A hybrid model combining VAE for design generation and RL for structural performance improvement.

Table I Optimization Results

Parameter	Before AI	After AI
Total Concrete Volume	980 m ³	812 m ³
Total Steel Weight	142 tons	119 tons
Estimated Cost	₹4.2 crore	₹3.55 crore
Total Savings	—	₹65 lakh

Observations

- Beam sizes were reduced while maintaining strength.
- Columns were optimized using tapered geometry.
- AI suggested redistributed reinforcement patterns improving load paths.
- Overall, 17% cost reduction achieved without compromising safety.

Challenges and Future Scope

Challenges

- Limited datasets for structural-specific AI training.
- Skepticism in industry due to lack of codified AI standards.
- Requirement of high computational power for complex simulations.

Future Scope

- Integration of AI into national building codes.
- Real-time optimization using IoT sensor feedback.
- Fully automated AI-driven design-to-site construction workflows.
- AI-based seismic optimization for earthquake-resistant structures.

III. CONCLUSION

Generative AI stands as a transformative force in civil engineering, offering unparalleled opportunities for structural design optimization and cost reduction. Through intelligent analysis, rapid design exploration, and data-driven decision-making, AI not only enhances engineering accuracy but also significantly reduces material and financial resource consumption. As the industry moves toward sustainable construction, AI-driven structural design will play a key role in shaping efficient, resilient, and affordable infrastructure globally.

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