

DESIGN-AWARE OPTIMISATION OF 2D SKELETAL STRUCTURES USING CGANS

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This research introduces an innovative diffusion-based cGAN framework for the automated generation of optimised 2D skeletal structures with Eurocode 3 (EN 1993-1-1) compliant steel Circular Hollow Section (CHS) assignments. Traditional structural optimisation methods such as Solid Isotropic Material Penalisation (SIMP) often demand significant computational resources and specialised expertise, creating barriers to widespread adoption.

The methodology comprises three integrated phases: comprehensive dataset generation, advanced diffusion-based cGAN training, and identification of sections assigned in the structural layout. The initial phase employs a computational pipeline that performs topology optimisation on simply supported frame configurations, incorporating skeletonisation, frame extraction, and size-layout optimisation while maintaining critical constraints, including a 0.3 volume fraction and penalisation factor of 3. This process yields optimised topologies that are subsequently enhanced with EN 1993-1-1 compliant CHS section assignments, rigorously evaluated for axial capacity, bending resistance, shear strength, and stability requirements specific to steel structures.

The core innovation lies in the diffusion-based cGAN architecture, which uniquely combines the strengths of both generative approaches. The cGAN component conditions structural generation on normalised input parameters through a sophisticated encoder-decoder generator paired with a discriminator. Simultaneously, the integrated diffusion process enables progressive refinement of generated structures through iterative denoising, producing high-fidelity 512×512 resolution outputs that maintain structural integrity. Key technical advancements include a hybrid training objective merging adversarial loss with diffusion-based denoising, conditional diffusion steps that preserve structural feasibility, and automated section assignments integrated directly into the generation pipeline.

Experimental validation demonstrates significant improvements over conventional methods, achieving approximately 50,000 times faster optimisation than traditional Finite Element Analysis (FEA)-based approaches, and perfect EN 1993 compliance in all section assignments. This work makes substantial contributions to both artificial intelligence and structural engineering by developing diffusion-based cGANs for high-quality structural generation, automating code-compliant section assignments within the Artificial Intelligence (AI) workflow, and delivering production-ready outputs requiring minimal post-processing. The framework's combination of computational efficiency and regulatory compliance makes it particularly valuable for rapid design iteration in steel structures, with future developments planned to incorporate 3D structural generation, more complex boundary conditions, and dynamic load considerations. By successfully integrating cutting-edge deep learning techniques with established engineering standards, this research establishes a new paradigm for intelligent, efficient, and regulation-compliant structural design automation.

Keywords: Artificial intelligence, Deep learning, Diffusion, Discriminator, Encoder-decoder, Finite element analysis, Generator, SIMP

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Design-Aware Optimisation of 2D Skeletal Structures using cGANs

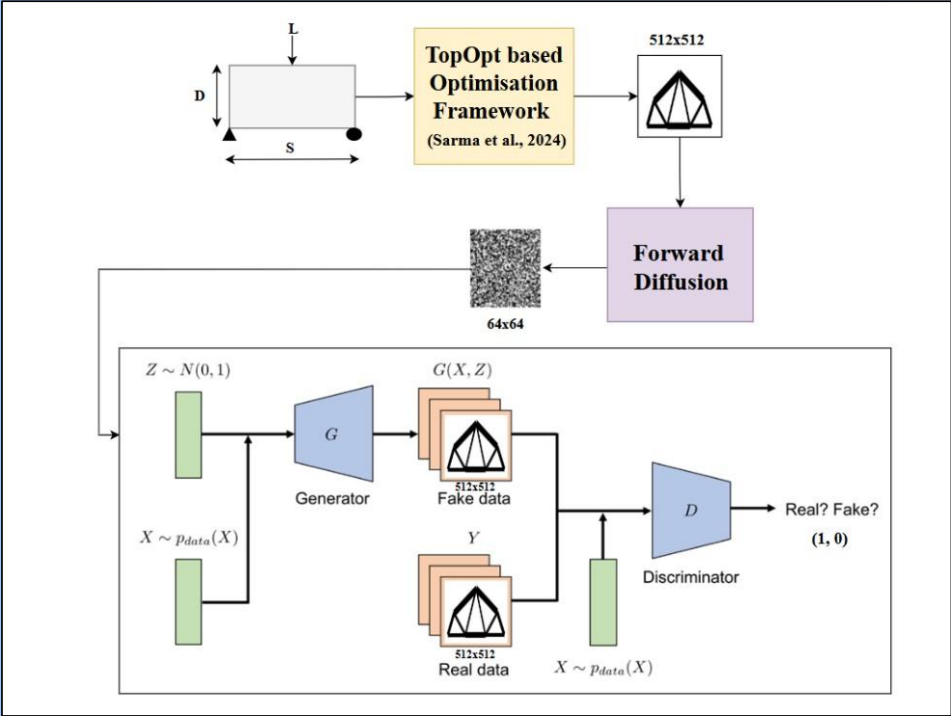
Traditional Optimisation Methods

Slow
Resource-intensive
Requires Expert Intervention



Technical Innovations

Hybrid adversarial + diffusion loss
Conditional generation on user inputs
Integrated section assignment



50,000x Faster than traditional methods



Higher accuracy than **DL** Methods (ACC = **0.963**, TPR = **0.918**, and TNR = **0.976**)



Perfect **EN 1993-1-1** compliance

Future Directions

3D structural generation
Complex boundary conditions
Dynamic load cases