DESIGN-INFORMED OPTIMIZATION OF 2D SKELETAL STRUCTURES USING CONVOLUTIONAL NEURAL NETWORKS

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Structural optimization aims to find the most efficient material distribution within a design domain by minimizing material usage, self-weight, and strain energy, while maximizing strength. Optimization approaches often use compliance as the objective function and volume as a constraint, which can result in designs that may not fully meet the practical requirements of civil and structural engineering due to potential inadequacies in structural integrity. To address this issue, design-informed optimization integrates structural optimization with design codes such as EN 1993-1-1, ensuring that optimized designs comply with structural integrity requirements and real-world applicability. Existing design-informed optimization algorithms typically rely on iterative schemes, which are computationally intensive and require specialized expertise. To overcome these challenges, this study introduces a novel computer vision-based framework that predicts design-informed optimized frames and accurately identifies member sizes using image processing techniques coupled with probabilistic section classifiers. This framework utilizes input parameters such as span, height, and load to predict the topology, size, and layout of optimized frames that satisfy structural adequacy criteria. It is particularly beneficial for assembly-based manufacturing, where precise member section prediction is crucial for construction efficiency and material optimization. The framework consists of three stages. In Stage 1, the CNN64 model generates a low-resolution layout of the optimized frame using input parameters such as span, height of the design domain, and load. In Stage 2, the CNN512 model refines this layout to produce a high-resolution image of the optimized frame, where section sizes are assigned. These models are trained on varying parameters including fixity, design domain, and load conditions. Stage 3 involves a member section identification algorithm that classifies the optimal structural section sizes through image processing techniques.

The efficacy of the framework was validated using simply supported and cantilever beam datasets, achieving pixel accuracies of 94.6% and 91.8%, respectively. Post-calibration, the section identification algorithm, which accounts for unavoidable errors such as generator residuals and section identification errors, achieved near 100% accuracy, demonstrating the robustness of the probabilistic section classifier. Compared to alternative architectures, the CNN64+CNN512 framework consistently outperformed others in metrics such as pixel accuracy, true positive rate, and binary cross-entropy in both datasets. It also demonstrated a significant reduction in computational loss, further confirming its computational efficiency. Overall, the analysis reveals that the CNN64+CNN512 model not only provides superior performance in prediction accuracy but also strikes an effective balance between computational efficiency and model complexity.

Keywords: Convolutional neural networks, Data-driven optimisation, Section identification, structural optimisation

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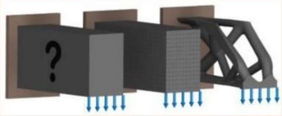
Background

Structural optimization



Finding the best material distribution

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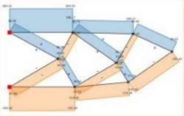
Integrity Check



design-code-based structural evaluation

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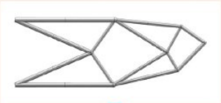
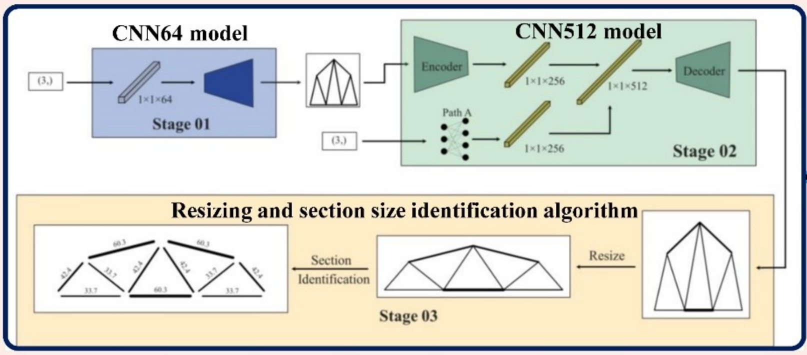
Design-informed optimization



A computationally expensive iterative algorithm

Proposed computer vision-based framework to reduce computational cost



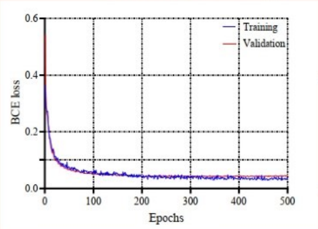
Stage 1 – Generates layout of the optimized frame

Stage 2 – Generates images of optimized frames in 512x512 resolution

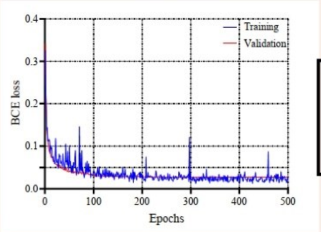
Stage 3 – Identification of section sizes

Results

Model Training



CNN64 with simply supported dataset



CNN512 with cantilever dataset

Evaluation of Stage 1 and Stage 2 models

Metric	**Simply supported dataset**	**Cantilever dataset**
Mean BCE	0.410	0.310
Pixel accuracy	0.946	0.918
True positive rate	0.874	0.807
True negative rate	0.967	0.948

Stage 3 as a classification

Identified thickness → Tolerance interval of equivalent thickness → Standard CHS