



**Politecnico
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Scuola di Dottorato ~ Doctoral School

WHAT YOU ARE, TAKES YOU FAR

Doctoral Dissertation

Doctoral Program in Civil and Environmental Engineering (38°Cycle)

Modern Paradigm for the Conceptual Design of Structures

A Cross-Disciplinary Method Applied to Footbridges Design

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Summary

The conceptual design phase determines a substantial share of the structural, environmental, and functional performance of infrastructure systems, yet it remains weakly formalised within structural engineering practice. Although early design decisions define structural topology, material strategy, robustness, and lifecycle behaviour, existing codes and analytical tools primarily address detailed verification and provide limited support for the systematic comparison of alternative concepts under uncertainty. This limitation has become increasingly critical as contemporary infrastructure projects require the early integration of structural performance, architectural quality, sustainability, and long-term resilience.

This doctoral research develops a cross-disciplinary decision-support framework for early-stage structural design, formalising conceptual design as a multi-criteria decision problem. The proposed method integrates architectural and planning quality, structural resilience, including resistance to disproportionate collapse, inspectability, and maintainability, and environmental and lifecycle performance, encompassing sustainability, circularity, and adaptability. A coherent system of quantitative indicators is defined to enable transparent, reproducible, and scenario-based comparison of conceptual alternatives prior to detailed analysis.

The methodology is operationalised through a dedicated Python-based computational tool that implements indicator evaluation, normalisation, weighting, and multi-criteria aggregation, and supports graphical exploration of trade-offs and interdependencies. The framework is validated through three real-world footbridge case studies, including design competitions and feasibility studies characterised by heterogeneous constraints and objectives. These case studies are employed primarily as methodological instruments to test, demonstrate, and refine the proposed framework rather than as isolated project analyses.

The results show that the proposed approach improves the explicitness and traceability of early-stage design reasoning, supports informed comparison of alternative structural concepts, and clarifies the implications of conceptual choices on long-term performance. The research positions conceptual design as a decision-critical and knowledge-intensive engineering phase and provides a methodological basis that can be extended beyond the specific case of footbridges.