REStructureD:
Resource Efficient Structural Design

NTNU and SINTEF

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Overview. The construction industry plays a pivotal role in shaping global greenhouse gas (GHG) emissions and material waste, largely due to its heavy reliance on resource-intensive materials like concrete and steel. In addition to the substantial carbon footprint of these materials, the demolition phase generates vast quantities of debris, a significant portion of which remains unused despite the potential for recovery and repurposing. Standardized structural design rules, while ensuring safety and functionality, typically adopt conservative assumptions that may lead to over-dimensioning of structural elements. They also offer limited guidance on circular design strategies, such as the reuse of components, resulting in the inefficient use of both new materials and existing resources.

Project Motivation. The objective of the *REStructureD: Resource Efficient Structural Design* project is to advance current practices by integrating three key elements:

1. *Risk-Informed Decision-Making*, which explicitly quantifies and manages uncertainties associated with loads, material properties, and other variables influencing structural performance;

2. *Parametric Design*, enabling an automated search for optimized structural configurations under multiple constraints and objectives;

3. *Circular Economy Principles*, emphasizing component reuse and waste minimization over the structure's entire life cycle.

This integrated approach seeks to address recognized shortcomings in everyday structural design. Standardized guidelines often do not adequately account for life-cycle implications, possible material savings, or the variability of reclaimed elements. By extending design boundaries beyond simplified safety checks, the project aims to propose a future-oriented framework that balances reliability, cost-effectiveness, and sustainability.

Limitations of Current Practice. Traditional structural design typically proceeds in two distinct phases:

- *Conceptual Design*, determining the overall load-bearing system, geometry, and material selection under broad architectural and economic constraints.
- *Detailed Dimensioning*, applying standardized rules for safety, serviceability, and durability verifications to size individual components (e.g., beams, columns).

While this approach streamlines routine engineering tasks, it often overlooks project-specific details and life-cycle considerations. The conservative nature of standardized design rules can result in suboptimal material allocation. Moreover, the framework seldom evaluates the embodied carbon in components or their potential reuse at end-of-life. Thus, achieving an optimal balance between safety, cost, and environmental impact remains challenging, especially when it comes to adopting circular strategies in everyday practice.

Risk-Informed and Parametric Design. Risk-informed design introduces explicit treatments of uncertainties in structural performance and user-defined objectives, offering a more transparent basis for decision-making than generic safety margins. Probabilistic models capture variations in material strength, loads, and degradation processes over time, allowing engineers to quantify the likelihood and consequences of failure. This probabilistic view can be integrated within a *parametric design* environment, where a design engine systematically searches a vast space of possibilities. By adjusting parameters such as span lengths, cross-sectional dimensions, and material properties, the parametric tool identifies solutions that minimize both economic costs and life-cycle GHG emissions, while maintaining adequate safety and serviceability levels.

Incorporating Circular Economy. A major obstacle to widespread reuse of structural elements is the uncertainty in their remaining load-bearing capacity. Reclaimed components may exhibit varying histories of stress, exposure, or damage, all of which can degrade performance. *REStructureD* aims to develop standardized protocols for data collection—covering aspects such as material specifications, exposure conditions, and usage history—alongside statistical models that estimate the probability distributions of key performance metrics (e.g., strength, stiffness). If additional information is needed, optional testing (destructive or non-destructive) can be used to reduce uncertainty about component properties, guided by a *Value of Information* approach. Thus, the decision to invest in testing is balanced against potential economic and environmental benefits stemming from component reuse.

Project Objectives. The *REStructureD* project sets out three main objectives to establish a novel framework for resource-efficient design:

1. **Develop a Risk-Informed, Multi-Parametric Structural Design Process.** This process will incorporate safety, economic, and environmental considerations, reflecting the full life-cycle of building structures. Design solutions will be automatically generated and optimized under multiple constraints, leading to more balanced and project-specific outcomes.

2. **Establish a Methodology for Reusing Reclaimed Structural Components.** The project will produce systematic procedures for the characterization and assessment of salvaged components. By integrating probabilistic models, engineers can confidently reuse elements, capitalizing on available data and targeted testing to ensure safety.

3. **Demonstrate Practical Application and Develop Digital Tools.** Through demonstrator case studies, the project's methods will be implemented and validated. These applications will compare traditional, rule-based designs with risk-informed, optimized solutions—showing possible savings in material, cost, and GHG emissions. The resulting open-access software tools will be designed for real-world use and disseminated widely.

Methodology and Work Plan. The research is structured into three work packages:

- *WP1: Risk-Informed Decision Framework for Structural Design.* This involves defining typical building systems, formulating objective functions that include life-cycle impacts, and integrating probabilistic safety constraints into an optimization model.

- *WP2: Methodology for Condition Assessment of Reclaimed Components.* Building on state-of-the-art data collection and tracking tools, WP2 will produce default probabilistic models for various component types, and procedures for reducing uncertainty via testing.

- *WP3: Validation, Digital Implementation, and Demonstration.* The project's findings will be compiled into user-friendly software capable of generating optimized designs for standard building configurations. This work package will also feature pilot examples—helping to illustrate and quantify the benefits of the new framework in real or representative scenarios.

Expected Outcomes and Impact. By merging advanced risk-based principles with parametric design and circular strategies, *REStructureD* seeks to reshape routine structural design practices. The project's outputs include:

- Reduction of material use and GHG emissions without compromising structural safety and serviceability.
- A clearer pathway for component reuse, enabled by solid scientific procedures and standardized protocols.
- Open-access digital design tools that allow practitioners to adopt these new methods in everyday projects.
- A foundation for future policy and standardization efforts, promoting a shift from generalized design rules to optimized and circular decision-making processes.

In essence, *REStructureD: Resource Efficient Structural Design* marks a significant leap toward more sustainable construction, demonstrating how risk-informed models, computational optimization, and circular economy thinking can be integrated to achieve designs that are at once safer, more economical, and more respectful of the environment. Through close collaboration with industry and standardization bodies, the project aims to drive a paradigm shift in structural engineering, enhancing resource efficiency at scale while meeting all requisite performance and reliability criteria.