Concrete matrices for high-cycle-fatigue resistant, eco-efficient infrastructure (2025-2031)

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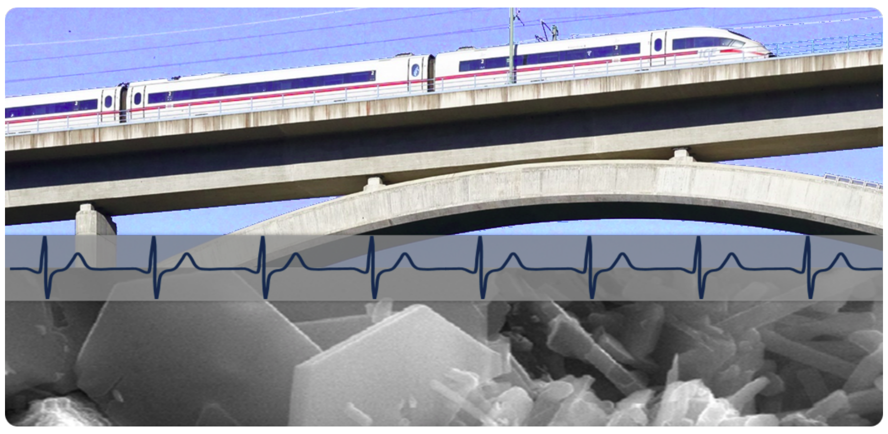
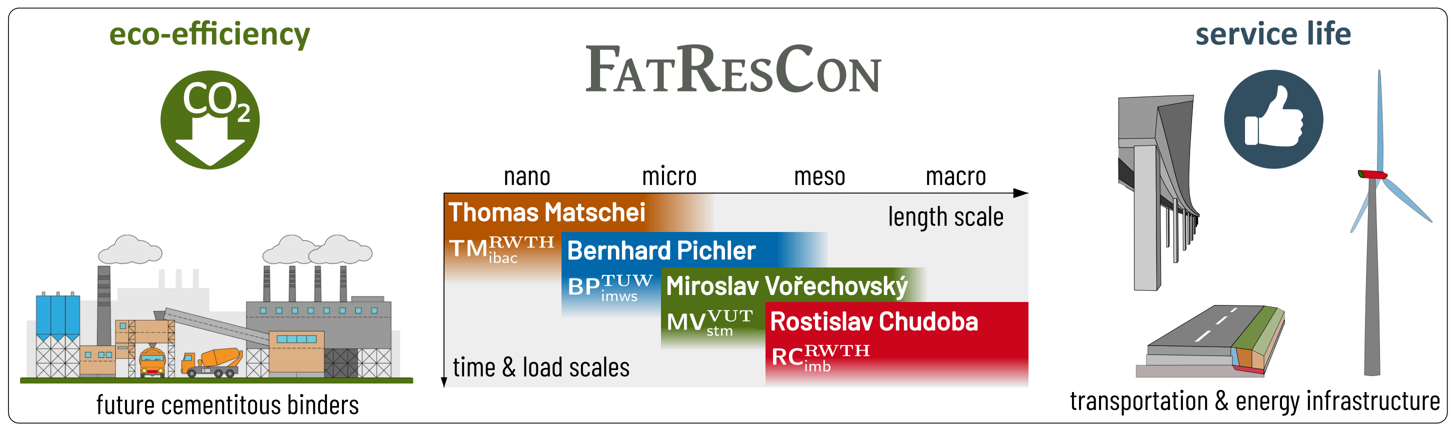
1. Project Overview





The necessity to meet the rising global demand for mobility and energy supply and, at the same time, the urgency to minimize the carbon footprint, leads to the challenging scientific question of the fatigue resistance of emerging eco-efficient concretes. Since existing knowledge of the traditional Portland-clinker-based binders is largely empirical, it cannot be directly transferred to new binder systems, exhibiting complex chemical and mechanical interactions within the heterogeneous material structure. In contrast to the well-established insight into the high-cycle fatigue of metals, a complete understanding of the fatigue degradation processes in concretes is still lacking. In this research, we are committed to pioneering an innovative approach that establishes a universally applicable link between the chemical/microstructural composition of novel concrete materials and their fatigue resistance. To create an interdisciplinary methodology for the scientific analysis of fatigue-resistant eco-efficient concretes, complementary competences of a multidisciplinary research team will be combined in a concerted application of physico-chemical modeling approaches of hydration processes and advanced methods of multiscale and multifield computational mechanics supported by machine learning and accompanied by a rigorous experimental validation program. The developed coherent methodical framework will include innovative theoretical and numerical as well as tailored experimental approaches covering all relevant spatial and temporal scales to enable realistic predictions of the fatigue behavior of existing and future eco-efficient concrete formulations. This is necessary to give design engineers confidence in the new materials, and to enable design concepts, optimally satisfying requirements for sustainable, economical, and reliable future transportation and energy infrastructure.

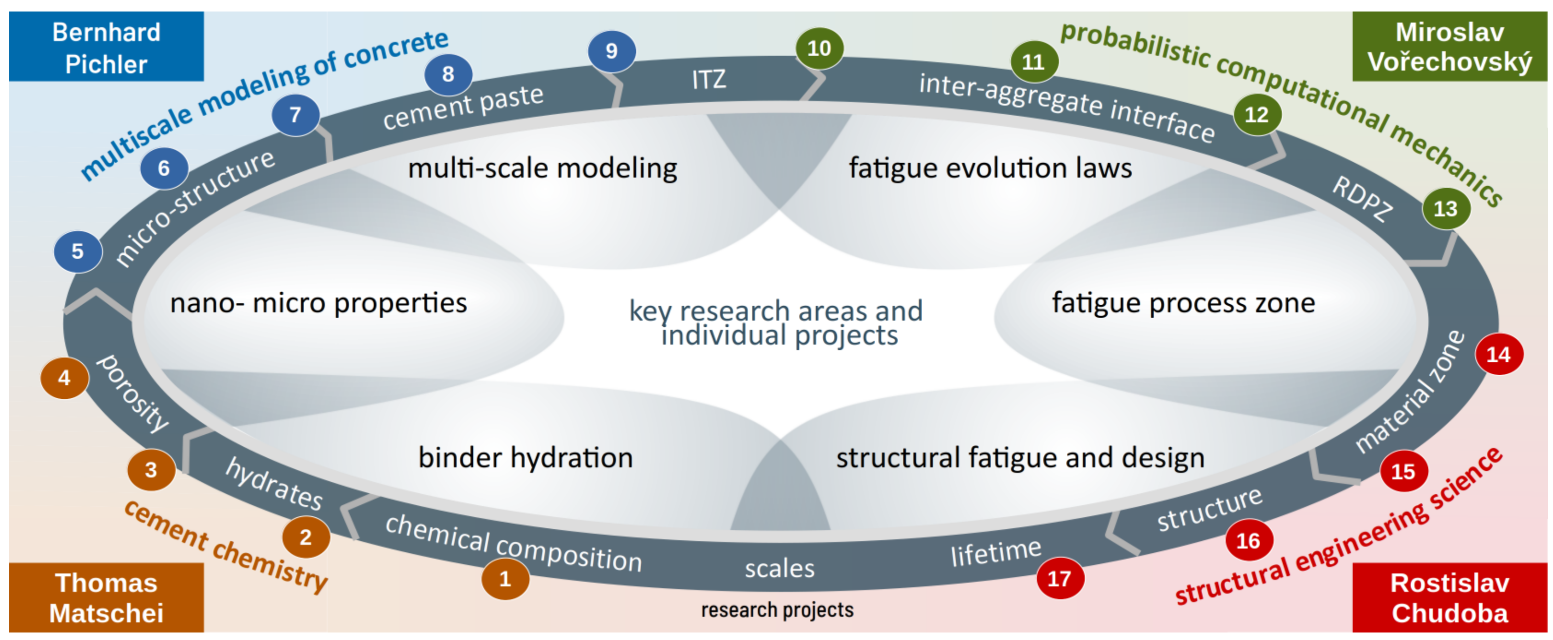
Why concrete? Concrete is a fundamental component of low- and high-performance structures worldwide. In the absence of alternatives, concrete will remain the most important construction material. Its massive use has been particularly increasing in critical infrastructure subjected to high-cycle fatigue loading, such as bridges, wind power plants, airport runways, and pavements.

Concrete fatigue, subtly operating behind the scenes at subcritical, pulsating load levels, leads to progressive material degradation and stress redistributions. This covert process eventually results in significant stress concentrations in the reinforcement, along with excessive cracking and pronounced deformations.

2. The Team

Our PI team comprises (from the left) Thomas Matschei, Miroslav Vořechovský, Rostislav Chudoba, and Bernhard Pichler, who lead this ERC Synergy effort. Supporting them is a dynamic cohort of about twenty PhD students and postdoctoral researchers. Together, we span experimental, theoretical, analytical, and computational specialties. Our approaches combine mathematical modeling, thermo-mechanics, chemistry, materials science, and data science. We probe the behaviour of concrete from atomic and microstructural scales to macroscopic structural levels. By integrating multi-scale computations, probabilistic theory, lab experiments, and chemical analysis, we aim to quantify and predict fatigue and degradation processes in eco-efficient concretes. This interdisciplinary team bridges physics, mechanics, and chemistry to reveal structure-property-lifetime links.

3. Synergistic Objectives and Backbone Research Hypotheses



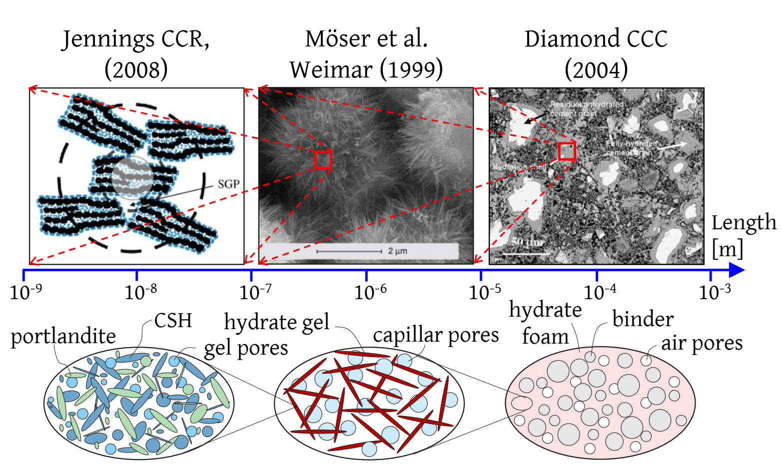
To address the **increasing global demand** for sustainable engineering infrastructure **without devastating the planet**, FatResCon is poised to revolutionize our scientific understanding of concrete fatigue as a paramount requirement for providing eco-efficient solutions.

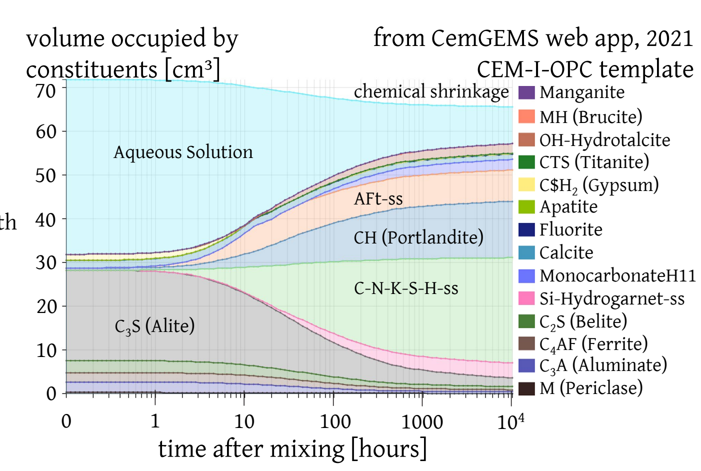
Our research endeavor marks the deliberate transition from traditional, empirically-driven techniques to modern, first principles-based research methods. Building upon identified knowledge gaps and leveraging our combined expertise in cement chemistry (TM), multiscale material science (BP), probabilistic computational mechanics (MV), and structural engineering science (RC), we proposed a meticulously formulated set of six key, interrelated hypotheses.

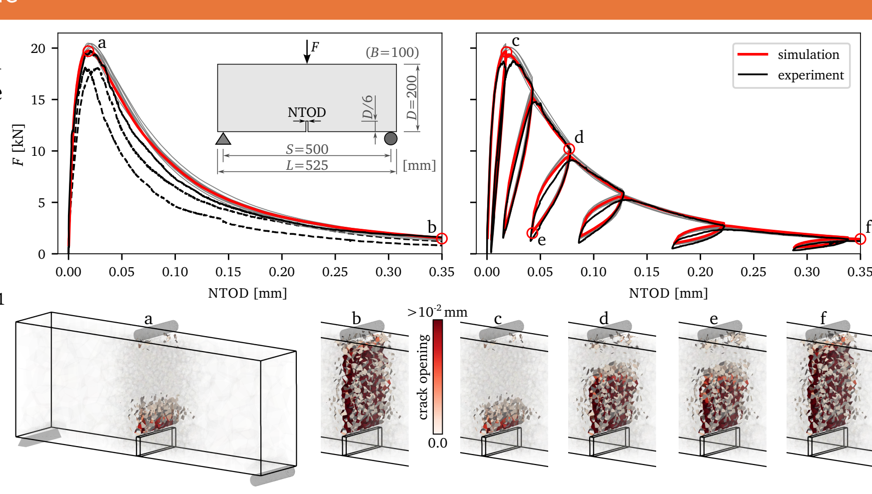
These **foundational hypotheses** form the backbone of the project and address all relevant spatial and temporal scales spanning from intricate details of chemical binder composition to the broad-scale prediction of fatigue life.

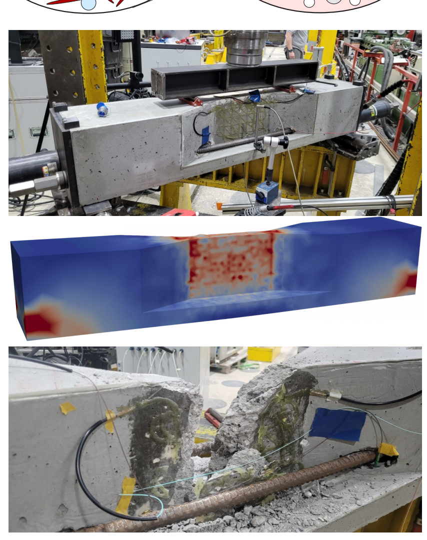
Our mission is to translate fundamental insight into predictive tools for durable infrastructure. Our effort will (i) result in deep scientific understanding and quantitative description of fatigue of eco-efficient concrete, (ii) enable innovative design concepts and practices satisfying the requirements for sustainable, economical, and reliable infrastructure, and (iii) make design engineers sufficiently confident to accept eco-efficient concrete with new binder compositions.

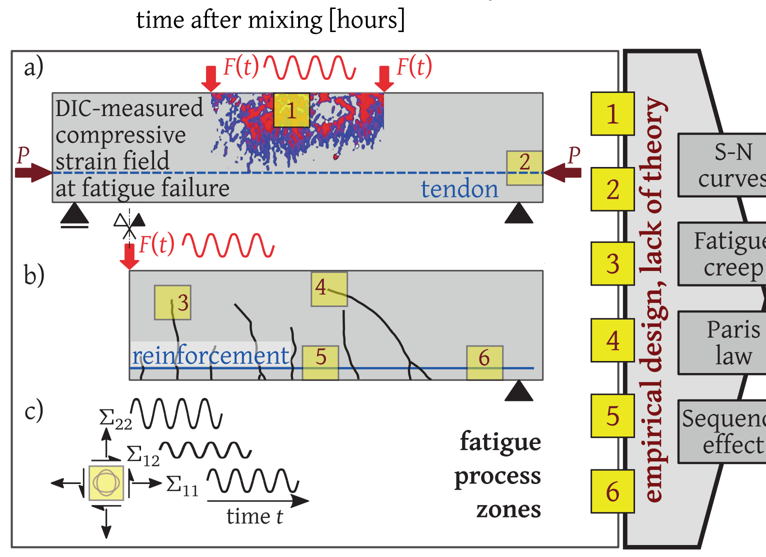
4. Multiscale Perspectives on Concrete Fatigue

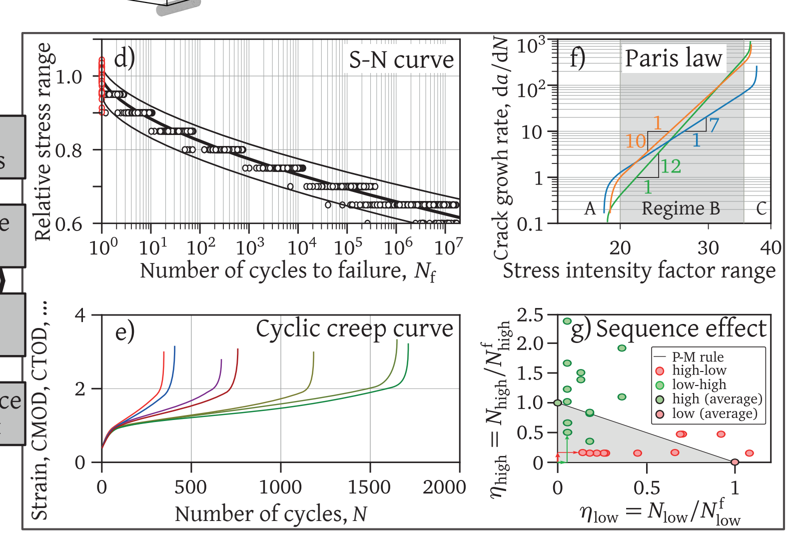












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Featuring: FATRESCON PROJECT

Interview with Miroslav Vořechovský (Brno University of Technology)

The FATRESCON project, funded by the European Research Council (ERC), is developing a groundbreaking methodology to connect the chemical composition and microstructure of new types of concrete with their resistance to fatigue. Unlike metals, the way concrete deteriorates under repeated stress is still not well understood. To tackle this challenge, researchers involved in the project will be combining advanced modelling, multiscale mechanics, machine learning, and experimental validation. Their goal is to create scientific tools that will help engineers design eco-efficient concrete for sustainable and long-lasting infrastructure.

Our PI team (from the left) T. Matschei, M. Vořechovský, R.Chudoba, and B. Pichler
Photo: B. Pichler

What is the aim of your ERC Synergy project FATRESCON and what makes it groundbreaking?
Our project tackles one of today's biggest infrastructure challenges: how to make concrete both sustainable and long-lasting. Concrete surrounds us in our everyday lives but producing cement (its key ingredient) generates about 8% of global CO_2 emissions, and many bridges, roads, and wind turbine foundations are wearing out far sooner than expected. A hidden culprit is fatigue: tiny cracks that grow under repeated use until they cause serious damage.

How challenging was the preparation of the ERC Synergy project proposal from your perspective as Corresponding Principal Investigator (cPI)?
FATRESCON assembles a multidisciplinary team of four Principal Investigators. This level of collaboration is unprecedented in concrete research; no single group could tackle the problem across all scales and disciplines. By uniting these perspectives, the project can attack the fatigue problem holistically, an approach only made possible by the ERC Synergy grant's collaborative model.
The preparation of the ERC Synergy proposal was both intellectually demanding and logistically complex. As the Corresponding Principal Investigator, I carried the responsibility of coordinating not just the scientific vision but also the communication among all team members, ensuring coherence and clarity across disciplines, institutions, and national systems. I think an important feature of our ultimately successful application was its rigorous scientific approach focusing on well-defined hypotheses, robust research tools, and a clear, coordinated plan.
One of the greatest challenges was crafting a truly integrated research concept—not just a sum of four strong research lines, but a unified, synergistic approach. The writing itself required extraordinary attention to detail, especially in expressing how our interdisciplinary collaboration would lead to breakthroughs that no single PI could achieve alone.

What makes the ERC Synergy scheme different from individual ERC grant schemes and what would you recommend to future candidates for this type of project?
The ERC Synergy scheme stands apart from individual ERC grants in both its ambition and collaborative depth. It's not simply about funding multiple PIs, it's about enabling a truly joint scientific effort. What makes it unique is the expectation that synergy is not optional, it is essential. The PIs must go beyond coordination and demonstrate genuine intellectual integration. This requires a deep level of mutual understanding, aligned vision, and trust.
From my experience, I would recommend to future candidates: start early and invest in team-building, focus on the synergy (not just the individual excellence), simulate the interview rigorously and ensure institutional support is in place.

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