Concrete Sustainability
Materials & Structures

Low-Carbon Concrete

International Conference - Malta 2025

Edited by
Ruben Paul Borg & Kamal H. Khayat

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Concrete Sustainability: Materials and Structures

Proceedings of the International Conference

Valletta, Malta – 12th December 2025

Organized by the

Faculty for the Built Environment
University of Malta

and the

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Cover Photo: 3D Printed Concrete, Ankara Turkey. SMACORT Project funded by Xjenza Malta and Tubitak Turkey: University of Malta and Hacettepe University Anakara (R.P.Borg)

Book Editing: Ruben Paul Borg (University of Malta)

The content of each abstract is the responsibility of the respective author/s.

The abstracts published in this book were presented during the International Conference CSMS 2025, organised by the Faculty for the Built Environment, University of Malta and *fib* The International Federation for Structural Concrete, at the Valletta Campus, University of Malta on the 12th December 2025.

ISBN 978-9918-0-1462-0

Publisher: University of Malta

December 2025

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Concrete Sustainability: Materials and Structures

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Preface

Concrete Sustainability: Materials and Structures 2025
fib International Conference

Prof. Ruben Paul Borg

Faculty for the Built Environment, University of Malta

The *fib* International Conference: Concrete Sustainability: Materials and Structures CSMS 2025 is the third International Conference, following previous events in the series organized at the University of Malta in 2018 and 2023, together with *fib* Commission 7: Sustainability and Task Group 7.8 Technical Meetings. The CSMS 2025 event is based on two complimentary actions: an international conference at the Valletta Campus of the University of Malta (12th December 2025) and a Workshop in Gozo (15th December 2025).

CSMS 2025 is dedicated to advancing knowledge, innovation, and collaboration in sustainable construction. The event brings together leading researchers, engineers, and industry professionals and is intended to highlight the latest developments in both fundamental and applied research on cement-based materials, advanced construction technologies, and sustainable structural design. CSMS 2025 addresses initiatives in low-carbon concrete technologies, recycling and reuse strategies, and performance optimization aimed at creating durable and resilient structures.

The conference features keynote lectures by Prof. Kamal Khayat, a globally renowned concrete experts, addressing High-Performance Concrete with Adapted Rheology, including design aspects and industrial applications, high-performance concrete and the emerging field of 3D-printed concrete.

The conference serves as a dynamic platform for sharing cutting-edge research, exploring industrial applications, and fostering global partnerships, CSMS 2025 seeks to accelerate the transition toward more sustainable and resource-efficient construction practices, covering key areas in cement-based materials and reinforced concrete structures, in particular the latest innovation and advancement in research and industrial applications towards sustainability and quality in construction. The conference presents the outcomes of research projects funded through Xjenza Malta, Horizon 2020 and Horizon Europe programmes. It also offers an opportunity for early career researchers and professionals to share their research work. The conference also includes a discussion forum on quality concrete, with the participation of leading experts and stakeholders in the industry in Malta.

The CSMS 2025 International Conference is organised by the University of Malta, Faculty for the Built Environment and *fib* The International Federation for Structural Concrete, in association with Xjenza Malta, through the Research Networking Scheme Project HIPERCRETE. The conference is also organised in collaboration with the Climate Action Authority, The Ministry for Justice and Reform in the Construction Sector, the Ministry for Gozo and Planning, and the US Embassy in Malta. I would like to acknowledge the Fulbright Programme which supported my academic activity during 2024 as Fulbright Scholar and visiting professor at the University of Missouri S&T USA, within the research group led by Prof. Khayat. I acknowledge the support of *fib* and its Secretary General Dr. David Fernandez-Ordonez in supporting the CSMS conference series. The conference is possible thanks to the contribution of many partners, who I acknowledge for their support in the scientific aspects and in the organisation of the event. I further acknowledge the experts who agreed to participate in the discussion forum and address the key issues in the concrete industry in the Maltese islands.

I acknowledge the collaboration of Philip A Tabone and Master Builders Solutions, who support the event with the objective of bringing together the academic community and industry partners. The conference is organised, with the support of leading Construction Industry organisations and entities: The Building and Construction Authority, the Kamra tal-Periti (Malta Chamber of Architects and Civil Engineers), Malta Chamber of Construction Managers, the Gozo Business Chamber, the Malta Group of Professional Engineering Institutions - Institution of Civil Engineers ICE UK, the Malta Developers Association, Sustainable Built Environment Malta & the International Initiative for a Sustainable Built Environment (iiSBE), Attard Bros., Central Cement Ltd, Penetron, MSM Polymers, CRDC, Controls and Concrete Plant International CPI Worldwide. Such collaboration between academia and industry strengthen the drive for quality in concrete construction, ensuring a greater understanding of advances in cement-based materials and low-carbon technologies.

The scientific contributions presented at the third *fib* International Conference being organised at the Aula Magna, Valletta Campus of the University of Malta, have a clear focus: low-carbon concrete, achieved through high-performance advanced materials. Low-carbon concrete mark a transformative evolution in contemporary building practice, integrating social, economic and environmental priorities, while directly contributing to climate-change mitigation and the development of adaptive, future-resilient built environments.

The International Federation for Structural Concrete (*fib*)

The fib, *Fédération internationale du béton*, is a not-for-profit association formed by 42 national member groups and approximately 2500 corporate and individual members in more than 100 countries. The fib's mission is to develop at an international level the study of scientific and practical matters capable of advancing the technical, economic, aesthetic and environmental performance of concrete construction.
The knowledge developed and shared by the fib including the fib Bulletins, fib events, fib workshops and fib courses, entirely the result of the volunteer work provided by the fib members.

The fib was formed in 1998 by the merger of the Euro-International Committee for Concrete (the CEB) and the International Federation for Pre-stressing (the FIP). These predecessor organizations existed independently since 1953 and 1952, respectively.

The University of Malta is an Associate Member of fib. The fib has supported the CSMS Conferences in Malta in 2018, 2023 and 2025. The University of Malta has also hosted fib Commission Meetings for Commission 7: Sustainability, and Task Group TG 7.8: *Recycled Materials and industrial by-products for high performance reinforced concrete structures*. The *fib* TG 7.8 is led by Prof. Ruben Paul Borg of the Faculty for the Built Environment University of Malta as Convener.

Professor Kamal Khayat, Keynote Speaker

Professor Kamal Khayat a globally recognized concrete scientist, joined Missouri S&T in 2011 as the Vernon and Maralee Jones Professor of Civil Engineering and Director of the Center for Infrastructure Engineering Studies. Between 8/2011 and 6/2014, he directed the Center for Transportation Infrastructure and Safety, a National University Transportation Center (UTC). The $37M grant funded 174 research, equipment, and education projects. He also directed the Tier-1 UTC, Research on Concrete Applications for Sustainable Transportation between 9/2013 and 12/2019. He was the Champion for the Advanced Materials for Sustainable Infrastructure Signature Area and the UM System's new Tier-2 Center for Novel Carbon-Efficient Binders for Sustainable Infrastructure.

Dr. Khayat received undergraduate, graduate, and postdoctoral degrees from the University of California, Berkeley. Between 1990 and 2011, Dr. Khayat was professor of Civil Engineering at the Université de Sherbrooke, Sherbrooke, Quebec, where he last served as Director of the Integrated Research Laboratory on Materials Valorization and Innovative and Durable Structures, a 40,000-ft^2 state-of-the-art facility made possible by a grant of C$16M from the Canadian Foundation of Innovation. At Missouri S&T, he led efforts to establish the Clayco Advanced Construction and Materials Laboratory – a 14,500-ft^2 state-of-the-art research facility inaugurated in 2020.

Professor Khayat is widely recognized as one of the world's leading concrete scientists. His pioneering work in the rheology of cement-based materials contributed to the pioneering of self-consolidating concrete (SCC). SCC has become the new normal in high-rise buildings, precast applications, and structural repair, given its potential to greatly improve construction efficiency and safety, reduce costs, and extend service life.

He has chaired/co-chaired several international conferences, including the 2020 Gordon Research Conference (Ventura Beach, CA), SCC2016 (Washington, DC), SCC2010 (Montreal), and other conferences in China, France, Poland, and the UAE. His outstanding and creative contributions to innovation, leadership, and technology transfer have been recognized by several international organizations, including the 2020 University of Missouri System President's Award for Sustained Career Excellence in STEM/Natural Sciences, the 2020 Robert E. Philleo Award, the 2018 Wason Medal, the 2017 J.-C. Roumain Award, and the 2015 Arthur Anderson Medal from the American Concrete Institute. In September 2019, he was honoured for his lifetime achievements in the field of SCC at an international conference in Germany held in his honour.

Professor Khayat was awarded over 143 research projects with approximate funding of $32M as PI and $14M as co-PI. He has advised 43 Ph.D. students, 46 MSc students, and 23 post-doctoral fellows and visiting scholars. He has co-authored over 500 publications, 11 contributions to books and book chapters, and served as editor/co-editor of 19 books and conference proceedings.

High-Performance Concrete with Adapted Rheology: From Design to Field Performance

Kamal H. Khayat

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Abstract

High-performance concrete with adapted rheology (HPC-AR) is carefully engineered to develop a specific set of rheological properties to enhance the performance of the material in fresh and hardened states. Examples of HPC-AR include underwater concrete, self-consolidating concrete (SCC), shotcrete, and 3D concrete printing (3DCP). Tailoring the rheological properties of concrete can affect key fresh properties of the material, such as the ease of mixing, placement, consolidation, and finishing as well as its resistance to bleeding, segregation, surface settlement, and washout. Rheological properties also influence some key properties of the hardened material, including formwork pressure, bond to reinforcement, and homogeneity of transport properties.

The presentation also discusses the basic notions of rheology of cement-based materials, rheological models applicable to cement-based materials, test methods to determine yield stress, viscosity, and thixotropy, as well as the relationships between rheological properties and workability of concrete. The advantages of tailoring the rheological properties of SCC to facilitate construction practices and enhance productivity are highlighted. Workability test methods to evaluate the flow characteristics of SCC are discussed, and performance-based characteristics for successful casting of different structural elements are presented.

The main parameters affecting concrete pumping are highlighted, including the rheological properties of the concrete and the lubricating micro-mortar layer formed between the bulk concrete and pumpline. Analytical models that can be employed to predict pumping pressure loss are presented, and comparison of such predicted pressure loss values to actual data generated through an extensive pumping campaign of high-strength concrete is featured.

The presentation also discussed mixture design methodologies to enhance the workability of fiber-reinforced composites, including superworkable fiber-reinforced concrete and ultra high-performance concrete (UHPC). The performance of the former HPC-AR used for the rehabilitation of a bridge deck in Missouri is discussed, highlighting the advantages of using this novel material to enhance constructability, reduce bridge deck cracking, and enhance service life of the structure. The presentation also discusses the effect of plastic viscosity on fiber orientation and distribution of self-consolidating UHPC and the effect of fiber distribution on flexural and tensile properties of UHPC made with 1%, 2%, and 3% micro steel fibers. The presentation reviews the functional requirements for 3DCP and highlights some offline test methods to evaluate the buildability and shape stability of 3DCP. A step-by-step methodology for the design of eco-friendly fiber-reinforced 3DCP is also presented.

Structural Health Monitoring of Reinforced Concrete Structures

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Abstract

The water tower located at the Marsa Abattoir represents a significant piece of industrial infrastructure that has undergone comprehensive restoration to address aging-related deterioration. The heavily deteriorated reinforced concrete Water Tower was restored using advanced technologies through a complex restoration strategy and strengthened through the application of advanced materials. Ultra-High Performance Concrete (UHPC) based on nano-materials and with self-healing properties was developed and applied to the column jacket, while Carbon textile reinforced concrete (TRC) was applied to the tank.

This paper details the design, strategic implementation, and commissioning of a Structural Health Monitoring (SHM) system installed as an integral component of the restoration strategy. The primary objective of the installation is to provide real-time, quantitative data regarding the tower's structural behaviour during critical phases of remedial works and its subsequent operational loading.

The methodology involved the deployment of a multi-modal sensor network strategically placed based on preliminary finite element analysis of critical stress points. The installed sensor network was successfully integrated with an on-site Data Acquisition System (DAQ) networked to a remote cloud-based visualization platform. The fully operational system now provides continuous data streaming, enabling the engineering team to validate restoration design assumptions, ensure site safety by identifying anomalous structural responses during active construction and commissioning, and establish a foundation for long-term predictive maintenance of the rehabilitated asset.

The Water Tower Restoration Project was funded by the Public Abattoir, the Planning Authority and the ReSHEALience Project through the Horizon 2020 (Research and Innovation programme, Grant Agreement No 760824).

Digital Inspection of Concrete Bridges in Coastal Areas

Carl James Debono[1], Ruben Paul Borg[2], Dylan Seychell[1], Vijay Prakash[1], Muhammed Ali Musarat[2], Saviour Formosa[3], Wei Ding[4], Jiangpeng Shu[4],

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[2] Faculty for the Built Environment, University of Malta

[3] Faculty for Social Wellbeing, University of Malta

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Abstract

Coastal concrete bridges play a crucial role in connecting regions and facilitating the movement of people and goods. This infrastructure is exposed to the harsh coastal environment including salt spray, high humidity, wind and possibly wave action that accelerate deterioration of key structural elements and reinforcement. Traditional inspection techniques are labour-intensive, time-consuming tasks, pose safety risks, disrupt traffic, and may struggle to reach difficult areas of the bridge.

The DiHICS project tries to address these challenges by combining a wall-climbing robotic platform, unmanned aerial sensing, and advanced computer-vision algorithms for defect detection and change monitoring. Imagery is captured by cameras mounted on an unmanned aerial vehicle or wall-climbing robot. Machine learning techniques are then applied on the imagery to identify cracks. The results are fed to a virtual-reality inspection environment to support decision-making.

This approach reduces manual inspection risks and avoids or reduces bridge closure, enhances inspection reliability and provides a digital baseline for long-term structural health monitoring and maintenance planning.

The DiHICS project is funded by Xjenza Malta under the SINO-MALTA Fund 2023 call for international cooperation in digital technologies.

Limestone Waste Recycling for Low-Carbon High-Performance Concrete

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Faculty for the Built Environment, University of Malta

Abstract

Large volumes of Construction and Demolition Waste, Excavated Waste limestone, Quarry Waste generated in the construction industry, present significant challenges in disposal with environmental impacts. Recycling presents opportunities in reducing the disposal of waste material and also resulting in lower demands on the extraction of new resources. However low-quality inert waste, which is generated in construction activities, presents limited opportunity in recycling, resulting in large volume of waste disposal. The project refers to the recycling of large volumes of excavation waste consisting primarily of lower quality limestone and other materials, normally considered inadequate if used as aggregate in civil engineering applications, primarily due to low mechanical characteristics and impurities. The Environment & Resources Authority reports that Malta alone generates about 1.5 million tonnes of C&D waste annually, which occupies almost 80% of the total waste generated in Malta (Environment & Resources Authority, 2021). Furthermore, cement as binder in concrete contributes significantly to greenhouse gases, responsible for approximately 8% of global CO_2 emissions.

The study aims to recycle large volumes of limestone waste as a byproduct of excavation waste in Malta, for the development of low-impact, high-performance concrete. The development of a high-performance concrete composite was achieved primarily using waste globigerina limestone powder through a new process based on alkali activation, and as an alternative to cement-based materials.

The waste material was processed through the innovative method and paste specimen were cast and tested for mechanical properties at 7, 14 and 28 days, achieving cube compressive strength exceeding 30 MPa. Mortar and concrete based on the new binder and with fine and coarse waste limestone aggregate in order to maximise the high-volume recycling of limestone waste, were then developed and analysed. The mortar and concrete specimen blocks achieved a high performance with compressive strengths exceeding 15MPa and with low porosity.

The high-performance composite produced entirely from waste, without the utilisation of cement or any other supplementary cementitious material as binder, supports low-carbon targets for construction materials. The research work aims to provide a novel and effective waste utilisation solution to convert large volumes of waste limestone into new building products.

The ReCON Project is funded by Xjenza Malta through the FUSION R&I Technology Development Programme.

Low-Carbon High-Performance Mortar for Retrofit of 20th Century Heritage

Ruben Paul Borg, Igor Semenov

Faculty for the Built Environment, University of Malta

Abstract

The conservation and adaptive reuse of historic buildings increasingly demand approaches that reconcile the preservation of cultural value with contemporary performance expectations, particularly in relation to energy efficiency, and structural performance and durability. This study presents a comparative analysis of five pilot interventions undertaken within the EU-funded SINCERE project, each addressing the integration of advanced mortar technologies into heritage contexts with diverse environmental, architectural, and regulatory conditions. The selected case studies encompass experimental and real-world applications across Israel, Spain, the Czech Republic, Greece, and Malta.

The research spans a variety of heritage typologies: four full-scale test cells at the Demo Park in Madrid; a brutalist university building in Holon, Israel; a steel-framed industrial structure in Ostrava, Czech Republic; a neo-classical Ottoman educational building in Rhodes, Greece; and an early twentieth-century coastal artillery searchlight post in Malta. Across these sites, novel mortar formulations, incorporating hempcrete, textile reinforcements, phase-change materials, and other functional additives, are evaluated in terms of their compatibility with heritage substrates, potential for thermal retrofitting, and resilience to environmental stressors.

A comprehensive sensor-based monitoring system underpins the thermal performance assessment. The controlled conditions at the Madrid site enable direct comparison of mortar variants subjected to identical climatic exposure. In Rhodes and Ostrava, material deployment is carried out within conservation regimes shaped by national heritage regulations. The Holon intervention explores retrofitting strategies suitable for occupied heritage buildings, where both architectural authenticity and functional continuity are preserved. The Malta pilot provides a unique testing ground for repair and strengthening mortars together with thermal renders purposely developed to a specific context and applied to concrete and limestone surfaces in a highly aggressive marine environment characterized by salt exposure and temperature variations.

Taken together, the findings demonstrate the capacity of advanced mortars to improve energy performance and material durability without compromising the historic integrity of built heritage. The study underscores the critical role of tailored material design, passive performance enhancement, and scalable monitoring methodologies in achieving sustainable retrofitting solutions, ultimately contributing to a practical toolkit for conservation professionals.

The University of Malta is a partner in the SINCERE Project (The second life of modern period architecture: Resilient and adaptive renovation towards net-zero carbon heritage buildings) which is funded by the HORIZON Europe Programme (Grant agreement ID: 101123293).

Additive Manufacturing of Low-Carbon Concrete: By-Product-Based and Alkali-Activated Mixes for Sustainable Construction

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[2] Hecettepe University Ankara, Turkey

Abstract

Additive manufacturing for concrete, 3D concrete printing, has attracted attention in construction and research projects worldwide. This technology involves building structures using concrete printed layer by layer. The construction industry adopted 3D concrete technology due to the advantages it offers including freedom in geometry, low cost, formwork-free, less human intervention, and safety. The concrete used in this technology has a strict requirement to achieve printability such as flowability, extrudability, and buildability. The common solution is to increase the percentage of the cement in the mixture to meet these requirements. As a result, the cement content needed for 3d concrete is higher than in conventional concrete which limits the sustainability of this technology. The University of Malta addresses this issue through two distinct studies aimed at enhancing the sustainability of 3D concrete printing.

The primary objective of the first study (3DConcrete Project) is to reduce the cement content in printable concrete by partially replacing ordinary Portland cement with industrial by-products including Maltese Globigerina limestone waste.

The second study (SMACORT Project) focuses on the use of an alternative binder, known as alkali-activated materials, as the main binder for printable concrete.

Both studies incorporate construction and demolition waste in the mix design to promote sustainability. In both studies, the developed mixes were evaluated to meet the printability requirements, including flowability, extrudability, and buildability. In addition, the fresh and hardened properties were investigated, along with durability aspects such as porosity and water absorption. Ultimately, these studies develop a novel type of 3D-printed concrete that delivers both economic and environmental advantages, offering a promising pathway toward sustainable and low-carbon construction through 3D concrete printing.

The 3DConcrete Project is funded by the Research Excellence Programme, Xjenza Malta. The SMACORT Project is funded through the Xjenza Mata – Tubitak Programme.

Waste Glass as a Binder in Low-Carbon Cement-Based Materials

Mirabel De Gabriele, Ruben Paul Borg

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Abstract

The construction sector contributes to the significant consumption of natural resources and the production of large quantities of waste materials. It is a major contributor to greenhouse gases, leading to global warming and climate change mostly due to the production of cement. Globally, waste glass is generated in large quantities but offers opportunities for recycling. In the local scene, it was revealed that the management of glass waste is a continuous challenge. It is often a loss-leader due to the absence of a glass waste recycling plant in Malta which leads to its transportation overseas for its management and recycling to avoid dumping in landfills. Moreover, recycling of glass waste generates a significant carbon footprint due to the high melting point of glass. Furthermore, recycling coloured glass is challenging due to the colour specificity.

The aim of the study is to propose solutions to the glass waste problem by studying different types of glass waste present in the local scenario. Their effective utilisation by transforming the waste glass into a powder to be used as a binder, as supplementary cementitious material in low-carbon cement-based materials was investigated. The effects of contamination, colour and heat treatment of the waste glass were addressed in this research.

This repurposing of glass waste can potentially reduce the strain of glass waste on local institutions involved in waste management. The various samples of waste glass powder were used as partial cement replacements in paste and mortar. Characterisation testing was conducted on the waste glass powders to determine their properties. The testing of the fresh and hardened properties of paste and mortar samples was carried out with the objective of gaining knowledge on the materials' behaviour. Noticeable trends appeared which showed that waste glass powder, even with contamination, has great potential to be used as a supplementary cementitious material that, in the long run, outperforms the traditional cement construction products, especially when heat treatment at effective temperatures is carried out.

The GLASS_Cem Project is funded by Xjenza Malta through the FUSION R&I Technology Development Programme Lite.

Sustainable Plastic Waste Recycling in Concrete

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Abstract

The project advances a scientifically rigorous approach to transforming hard-to-recycle plastic waste into low-carbon construction materials, addressing two converging global challenges: the accumulation of non-recyclable plastics and the environmental burden of conventional concrete production. Globally, only 10% of plastic waste is recycled, while Malta records similarly low recycling rates, with approximately 80% of plastic waste remaining unused. Meanwhile, cement production alone contributes roughly 8% of global CO_2 emissions, and concrete manufacturing continues to rely heavily on energy-intensive processes and extraction of natural aggregates. The SPARC Project, developed in partnership between MSM Polymers Group, CRDC Materials and the University of Malta's Construction Materials Engineering group responds to these challenges by engineering upgraded formulations of RESIN8, a synthetic lightweight aggregate manufactured predominantly from end-of-life plastics.

The project focuses on replacing high-impact components of the existing RESIN8 formulation, specifically coal fly ash and slaked lime, with sustainable and abundantly available mineral substitutes sourced from European waste streams. Proposed alternatives include biogenic ashes, glass pozzolans, silica fume, steel slag, and other circular by-products. Through extensive laboratory investigation, including rheological assessment, mechanical performance evaluation, durability testing, thermal characterization, and life-cycle assessment, the project aims to scientifically validate new RESIN8 variants that deliver equal or enhanced functional performance while significantly reducing embodied carbon and resource depletion.

These products are designed for use in creating sustainable construction materials. By increasing the recycling of plastic waste, the project not only mitigates environmental threats but also produces construction materials with enhanced strength, reduced weight, and lower environmental impact, promoting a circular economy approach to plastic waste management and sustainable construction applications. This research is designed to support Malta's national transition toward a circular, low-carbon construction ecosystem.

The SPARC Project is funded through the Xjenza Malta TESP Technology Extension Support Programme.

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ISBN 978-9918-0-1462-0