Concrete Sustainability
Materials & Structures

International Conference - Malta 2023

Edited by Ruben Paul Borg

L-Università ta' Malta

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Concrete Sustainability: Materials and Structures

Proceedings of the International Conference

Valletta, Malta – 21st November 2023

Organized by the

Faculty for the Built Environment
University of Malta

and the

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Cover Photo: The *Qajjenza* Folded Plate Reinforced Concrete Structure (R.P.Borg)

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 2023, organised by *fib* The International Federation for Structural Concrete and the Faculty for the Built Environment, University of Malta, at the Valletta Campus, University of Malta on the 21st November 2023.

ISBN 978-9918-0-0704-2

Publisher: University of Malta

November 2023

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Concrete Sustainability: Materials and Structures

International Conference organized by

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Preface

Prof. Ruben Paul Borg

The *fib* International Conference: Concrete Sustainability: Materials and Structures CSMS 2023 Malta, is the second International Conference, following the first event in the series organized at the University of Malta in 2018. The *fib* International Conference is organised on the occasion of the second *fib* (The International Federation for Structural Concrete) scientific activities in Malta during 20th to 22nd November 2023, including the *fib* Commission 7 Task Group 7.8 Meeting. The TG 7.8 addresses Recycled Materials and Industrial by-products for high performance reinforced concrete structures, within *fib* Commission 7: Sustainability of Concrete and Concrete Structures.

The conference covers 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 is based on four main sessions, with high quality presentations from key experts in the field. The conference also offers an opportunity for early career researchers and professionals to share their research work through conference presentations and poster sessions. Further to the call for abstracts and review process, the quality of contributions suggests the publication of high impact scientific contributions. The conference also includes discussion fora, with the participation of leading experts and stakeholders in the industry in Malta. The three fora address the following key areas: Quality Concrete; Sustainability of Concrete; Historical Developments of Concrete in Malta.

The CSMS 2023 International 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 am grateful for the support of the Task Group 7.8 expert members who agreed to support the conference coinciding with the scientific gathering of the Task Group in Malta; the Chairman of *fib* Commission 7 Prof. Domenico Asprone, past Commission 7 Chairman Prof. Petr Hajek and the Secretary General of *fib* Dr. David Fernandez-Ordonez. I further acknowledge the experts who agreed to participate in the discussion fora and address the key issues in the concrete industry in the Maltese islands.

I acknowledge the support of Philip A Tabone together with Master Builders Solutions and Controls, who agreed to support this key event and for the effort to ensure a successful conference with the objective of bringing together the academic community and industry partners. Such collaboration between academia and industry, strengthen the drive for quality in concrete and promotes a greater understanding of advances in cement-based materials and reinforced concrete structures. The conference has been organised, in association with the leading Construction Industry organisations and entities in the Maltese Islands, who further supported *fib* and the University of Malta: the Ministry for Public Works and Planning, Planning Authority, Building and Construction Authority and the Occupational Health and Safety Authority of the Government of Malta, the Chamber of Commerce, Kamra tal-Periti (Malta Chamber of Architects and Civil Engineers), Chamber of Engineers, Malta Chamber of Construction Managers, 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), Bank of Valletta, AX Group, Attard Bros. and Concrete Plant International CPI-Worldwide.

The scientific contributions presented in the second *fib* International Conference being organised at the Valletta Campus of the University of Malta, cover a range of advances in cement and concrete.

However, the conference has a clear focus: concrete sustainability achieved through resource efficiency and high-performance advanced materials with low environmental impact, addressing societal needs and economic demands, towards durable and safe reinforced concrete structures.

The conference sets the scene for a continued dialogue towards a framework for improved quality in concrete and construction in the Maltese Islands.

Concrete Sustainability: Materials and Structures

Ruben Paul Borg

Faculty for the Built Environment, University of Malta, Malta
fib Commission 7 Sustainable Concrete TG7.8 Convener

Concrete Sustainability refers to materials and structures which have sufficient strength and durability throughout their life cycle, in intended applications. As concrete stands as the most extensively utilized construction material on a global level, exploited widely in structures and infrastructures, its environmental impact is substantial, characterized by increasing carbon emissions and escalated consumption of raw materials. Cement and Concrete have a significant impact on the environment; the cement production industry contributes to a significant quantity of the global carbon emissions with 1 ton of CO_2 resulting for every ton of cement produced.

Concrete sustainability further promotes effective use of resource and waste, exploiting the potential for waste material and industrial by-products, reducing demands on natural resources whilst exploiting the recycling of materials with reduced volumes of waste disposal. Industrial by-products exploited as supplementary cementitious materials tend to improve the durability of concrete.

As a consequence of the negative environmental impact of concrete, innovations aimed at enhancing the sustainability of concrete assume paramount importance in furthering Climate Action within the construction industry. The pursuit of concrete sustainability led to notable innovations in new composite materials and advanced technologies towards ecologically friendly, financially viable, and operationally effective solutions.

The development of new materials and innovation in cement based composite materials including ultra-high performance concrete, self-healing and nano-based materials and bio-materials, lead to more durable concrete and reinforced concrete structures with improved performance throughout their life cycle. Advanced materials help achieve more economic structures when considering the whole life cycle, with increased safety during their service life, lower demands for repair and maintenance leading to significant economic advantages. New production technologies and advances in additive manufacturing further support this drive towards high performance and concrete sustainable.

Concrete as a complex composite material can be engineered to specific performance requirements. Sustainable use of concrete is achieved through innovation in materials and structural systems, together with a greater appreciation of optimised solutions for intended applications. Concrete quality has a key role in the development of cement based composite materials with reduced environmental impact, supporting concrete sustainability.

Innovation in academic research and developments in industry are key towards effective solutions intended to address the demands for greater efficiency and economy, safety of structures and environmental protection.

fib Commission 7: Sustainability

The main objective of *fib* Commission 7 is to develop a strategy for the integration of sustainability issues in the design, construction, operation and demolition of concrete structures. Design concepts of concrete structures should be based on a sustainability framework considering environmental, economic and social aspects. The key activities of Commission 7 are focused on the following: the reduction of CO_2 emissions from concrete production; the reduction of energy use for construction and the operation of buildings (including thermal mass effect); improving the performance quality of the internal environment (acoustics, thermal well-being, etc.); the reduction of waste to landfill; the development of sustainability metrics and data requirements needed for Environmental Product Declarations and other quality assessment; recycling and use of recycled materials (including recycled concrete); resiliency of structures; and related areas. The goal of the Commission is to support a framework for the sustainable design of concrete structures, implemented in the new *fib* Model Code MC2020.

Recycled materials and industrial by-products for high performance reinforced concrete structures

Task Force 7.8 within Commission 7 addresses recycled materials and industrial by-products for high performance reinforced concrete structures. The objective of TG 7.8 is to address the sustainable use of materials through the effective exploitation of waste materials and industrial by-products, for the production of high-performance concrete with enhanced durability. The objective of the TG 7.8 is to highlight critical aspects in current practice in waste recycling and use of secondary materials for high performance concrete. It shall address the state of the art, best practice and also identify and analyse gaps in the exploitation of waste materials with potential for delivery of high-performance durable concrete. The task group aims at developing a framework for guidelines to help different stakeholders involved within the recycling industry and the producers of HPC, in order to facilitate the production and classification of materials but also their exploitation for HPC optimisation.

The Task Force addresses the following key areas:

- The production of high-performance concrete based on waste and industrial by-products.
- Use of waste materials as a substitute for aggregate
- Use of by-products as supplementary cementitious materials.
- Resilience of reinforced concrete structures with improved structural performance through the application of industrial by-products for safe structures, promoting sustainability practices.
- LCA applications & integrated end of life considerations for waste recycling to produce high performance concrete.
- Framework for Guidelines for the production and classification of waste and its application in high performance concrete.

The Commitment of the *fib* SAG Sustainability initiative and Commission 7 towards sustainable concrete structures

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Abstract

Traditional design approaches often prioritize compliance with prescriptive codes and standards, overlooking the broader societal, environmental, and economic implications of concrete structures. This gap in understanding necessitates a shift towards performance-based design, which prioritizes achieving specific performance. New approaches are expected to offer a more rational and tailored methods to structural engineering, enabling designers to tailor the design to the specific needs of the structure and its intended use. This would allows for the exploration of innovative structural solutions and materials, potentially leading to significant reductions in embodied energy, carbon emissions, and resource consumption.

However, existing design methodologies are primarily developed for conventional concrete structures and may not adequately accommodate the diverse range of non-conventional solutions. To address this, it is crucial to develop performance criteria specifically tailored for these unconventional approaches and to establish verification frameworks that can assess their performance using models, testing, or a combination of both. Moreover, limited knowledge of methodologies for guiding decision-making towards optimal structural solutions in terms of environmental impact, while still satisfying expected structural, functional, and economic performances, hinder the widespread adoption of innovative solutions. Evaluation of best practices plays a crucial role in facilitating knowledge dissemination and fostering a collective commitment to sustainable design within the concrete construction sector.

- Enhancing the sustainability of concrete structures is crucial to achieving global carbon neutrality by 2050. The fib SAG Sustainability initiative and the Commission 7 will spearhead this effort by focusing on key objectives:
- Identifying Optimal Sustainable Structural Solutions, exploring a range of innovative materials, structural designs, construction techniques, maintenance approaches, and circular economy strategies to minimize the environmental impact of concrete structures.
- Enabling Performance-Based Design of Sustainable Structures, to ensure the consistent application of safety principles in structural design for innovative solutions. This will involve reassessing reliability requirements, uncertainty treatment, and establishing performance evaluation frameworks supported by material and structural testing.
- Developing Decision-Making and Assessing Tools for Sustainable Structural Solutions, elaborating on multi-criteria decision-making processes to guide the selection of sustainable structural solutions that meet environmental, structural, functional, and economic requirements, proposing effective strategies to ensure that decision-making throughout the design process aligns with sustainability goals.

Through these objectives, we intend to contribute significantly to the development of sustainable concrete structures and support the global transition towards a carbon-neutral future.

Performance-related approaches to use of waste materials in concrete structures

Kevin Paine

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Abstract

Recycled aggregates, sourced from construction, demolition, and excavation waste, often face an unjust perception of inferiority compared to their natural counterparts, primarily due to perceived drawbacks in porosity and strength. This has resulted in distinct treatment within industry standards, limiting the utilization of certain high-quality recycled aggregates.

For example, EN 12620 imposes specific requirements on the composition of normal weight recycled aggregates. However, this composition-centric approach fails to acknowledge the vast performance variations within recycled aggregates of similar compositions, and that concrete made with these different recycled aggregates will differ widely in strength, deformation characteristics and durability despite nominally being of similar composition.

As an alternative, previous research has laid the groundwork for a performance-related approach, aiming to better integrate the treatment of normal-weight recycled aggregates under EN 12620. This approach recognized that four properties of recycled aggregate, (i) water absorption (ii) Los Angeles value, (iii) drying shrinkage and (iv) particle density, could identify the most significant differences in the performance capability of recycled aggregates [1]. Consequently, three classes of recycled aggregate were generated, independent of composition, that provided a suggestion on their use in appropriate concretes.

Since this research was published, Silva et al. [2] further refined this approach by arguing that drying shrinkage was unnecessary. Consequently, Ma [3] has suggested that only water absorption, perhaps on the recognition that it tends to correlate closely to Los Angeles value and density, and is the simplest of the tests to carry out, is suitable for defining recycled aggregate quality alone.

Expanding upon these foundations, the research in this paper re-examines further work that was carried out to establish whether these properties of aggregate were suitable for defining the compressive strength, load-dependent, and load-independent deformation characteristics of concrete [4]. A diverse pool of 30 aggregates—normal-weight, natural, recycled, and manufactured – were used to get a suitably wide range of properties within the normal-weight aggregate pool.

Overall, the results affirmed the viability of a performance-related approach and did identify water absorption as a particularly useful property for determining the effect of a recycled aggregate on the deformation characteristics of concrete. However, alone, it is likely that this single property will miss some idiosyncrasies in recycled aggregate performance.

The author considers that by adopting a performance-related approach to recycled aggregate use in concrete, we have the potential to acknowledge the full range of recycled aggregates in concrete, encourage their broader adoption, and alongside this align with global sustainability objectives.

Keywords

Recycled Aggregates, Engineering Properties, Performance, Strength, Water Absorption.

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Use of ceramic industrial and construction waste as aggregate for concrete

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Abstract

Sand, gravel and crushed stone (aggregates in general) are the most extensively extracted materials from the Earth [1]. Aggregate production is considered to be approximately ten times the cement production. In 2017, worldwide cement production reached an estimated 4.1 billion tons, resulting in a global aggregate production of 41 billion tons [2]. To mitigate the environmental impact associated with concrete manufacturing, recent efforts have focused on exploring the use of recycled aggregates from sources such as demolitions, concrete plants, industrial byproducts, and other waste materials. Only a few countries, including Belgium, Malta, the Netherlands, and the United Kingdom, use more than 20% recycled aggregates in their construction projects. In contrast, in Spain construction employs only 2% of aggregates of recycled origin [3]. The Spanish Structural Code, released in 2021, allows the use of recycled aggregates for structural concrete, but limits it to materials derived from recycled concrete waste, excluding other origins. These other materials, for example those of ceramic origin, could be used for the manufacture of non-structural concrete complying with the code. Ceramic materials have good compatibility with concrete and in general, they are materials resistant to abrasion and heat with a low coefficient of thermal expansion, in addition to chemical inertness and great longevity. In Europe, the ceramic industry produces 25% of the world's ceramic production, and much of that production comes from Spain, which in 2021 was the fourth largest producer in the world [4]. On a national level, 94% of the Spanish ceramic industry is concentrated in the province of Castelló.

This study explores the feasibility of replacing natural aggregate in concrete production with ceramic waste, specifically analyses two types of industrially recycled ceramic aggregates: a white paste and a red-mixed paste ceramic, each one obtained in two granulometric fractions. White paste ceramic consists of stoneware and porcelain stoneware tiles, known for their high strength and low porosity. The study analyzes properties like size distribution, water absorption, wear resistance, and density, comparing them to values obtained from the literature for recycled ceramic aggregates. The results suggest that white paste ceramic aggregates have promising properties and meet the water absorption limits for recycled concrete aggregates (7.5%) as per the Spanish Structural Code (Fig. 1). However, red-mixed paste ceramic aggregates, particularly the sand fraction, exhibit high water absorption, which may raise concerns. Additionally, challenges were detected to achieve a continuous size distribution for white paste aggregates due to their strength and hardness, which could lead to adjustments in the mix designs to prevent segregation. Despite these challenges, previous research [5] has demonstrated the feasibility of using these white paste ceramic aggregates in concrete production.

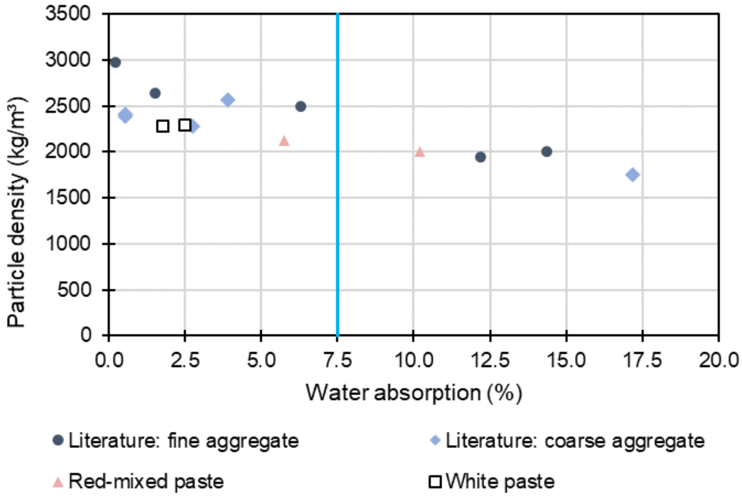

Fig. 1. Particle density vs water absorption of recycled ceramic aggregates, data obtained from the literature and from experiments.

Keywords
circular economy, ceramic waste, physical properties, recycled aggregate concrete

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Plastic waste as a concrete mix component

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Abstract

In the last decades, several strategies have been employed to improve the characteristics of concrete in terms of mechanical strength, ductility, durability, lightness, workability, ability to prevent the oxidation of steel reinforcement, etc. In this study a new point of view is faced, that is the possibility to use concrete as a container of waste without worsening, or containing the worsening, of the properties mentioned before. In detail, it is investigated the possibility of recycling plastic waste in different forms, by using it as aggregate in the production of concrete. The exploitation of waste, or byproducts, as alternative aggregate in concrete, and in detail is not new and results in a reduction in the exploitation of scarce natural resources. Productive use of waste leads to a reduction in the landfilling of waste through the transformation of waste into a resource. Here, plastic is not properly considered as a resource while concrete is considered a resource to limit the introduction of plastic waste in the environment.

The introduction of plastic waste in the concrete is not new [1-12] but in many cases, the waste is transformed before its use. Introducing not transformed plastic waste into ordinary concrete mixes is a challenge because, in connection with the characteristics of the plastic waste, the risk of a loss of performance is not so low.

To prove the possibility of reaching this objective with an acceptable loss of performance, the mechanical characteristics of concrete mixed with additional alternative plastic aggregates classified as waste are investigated and discussed in this paper. The experimental program includes the inclusion of different types of plastic wastes (different refers to the chemical composition and to the shape of the plastic aggregate) in the concrete. Different mixes with different percentages of waste are investigated to identify possible fields of application. The experimental results indicate that the use of plastic waste is possible within significant percentage ranges.

Keywords

Concrete; Waste Recycling; Plastic; Mechanical Performance

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The production and use of Libyan metakaolin in Concrete

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Abstract
The use of supplementary cementitious materials SCMs such as metakaolin (MK) may replace part of the cement to enhance the mechanical properties and durability performance of the concrete and to mitigate the CO_2 footprint resulting from the cement production. Unlike other by-products SCMs, which can have different compositions, MK is produced under carefully controlled conditions. As such, a much higher degree of purity and pozzolanic reactivity can be assured. This paper studies the potential of Libyan clays to produce metakaolin and its use in concrete. Nine natural clay samples were collected from different locations in Libya. The clays were analyzed before and after calcination at 700 °C for 2 hours for their potential to produce metakaolin. The characterization was made using an X-ray fluorescence spectrometer (XRF), X-ray diffraction (XRD), differential thermal analysis (DTA/TG), scanning electron microscopy (SEM), energy dispersive spectroscopy (EDS), and Fourier transform infrared spectroscopy (FTIR). The results showed that six of the nine tested clays can be classified as kaolinite clays, and Libyan metakaolin (LMK) can be produced from them with less energy and CO2 emissions than OPC. On the basis of the characterization and its abundance, Samnu clay was selected for further assessment. The LMK considered was produced by de-hydroxylation of Samnu kaolinite clay at 700°C for 2 h. Three sets of cement mortar with different LMK replacement levels (0, 5, 10, 15, 20, 25, and 30%) were prepared and tested for their mechanical properties at curing ages of 3, 7, 28, 56, and 90 days. The first set was prepared with a constant water/binder ratio (w/b) of 0.5; the second set was prepared with varying w/b ratios of 0.5–0.6; and the third set was prepared with a 0.5 w/b ratio and different superplasticizer (sp) dosages (1–1.5%). Furthermore, a set of cement paste samples with the same replacement levels and curing time were prepared and tested to determine vacuum saturation porosity and water sorptivity. The results confirmed the potential use of LMK up to 30% with noticeable improvements in the mechanical properties and durability.

Keywords: Libyan clays, Libyan metakaolin, clay characterization, metakaolin paste and mortar

Alkali activated binding composition with phosphogypsum

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Abstract
Ordinary Portland Cement (OPC) concrete is most popular building material. However, OPC production requires a lot of energy and consumes a lot of natural raw materials. CO_2 emitted during the manufacturing of OPC which pollutes the environment. New types of binders, such as alkali activated binders, could be an environmentally friendly alternative to OPC systems. Aluminosilicate precursor and alkali activator should be used to produce alkali activated binders. Calcium-based additives have a significant influence on the main properties of alkali activated binders. The hardening of alkali activated systems are close related with the addition of calcium cations as stated Davidovits [1]. In the alkali activated systems different types of compounds with calcium cations could introduced. Aboulayt et al. [2] investigated the influence of calcite on the alkali activated metakaolin system. It was concluded that calcite acted as micro filer and do not react with another components, do not form new compounds. Another type of chemical compound with calcium cations is CaO and $Ca(OH)_2$, which have been incorporated into fly ash geopolymers [3]. The mechanical properties of the samples with calcium compounds were increased by curing them at room temperature. However, when curing the samples at a higher temperature, i.e. i.e. at 70 °C, the mechanical properties were lower. Gijbels et al. [4] used the additive of phosphogypsum (PG) in alkali-activated ground granulated blast furnace slag system. This additive shortened initial setting time but prolonged final setting time. Higher polymerization level and positive mechanical properties development was reached for the samples with optimal amount of PG. The aim of this study is to investigate the PG additive on the main properties of alkali activated slag and biomass ash systems.
In the alkaline environmental PG reacted with sodium hydroxide according to Eq. (1):

$$CaSO_4\ 2H_2O + 2NaOH = Na_2SO_4 + CaOH_2 + 2H_2O \qquad (1)$$

New formed Na_2SO_4 is effective, well-known activator of alkali activated binders [5]. It takes part in the formation of new hydration products and in this way, it speeds up geopolimerization process (settings times become shorter). By using optimal amount of PG the positive compressive strength development was achieved with compact microstructure. Samples with PG have 1.2 times higher residual strength compared with samples without PG. This means that alkali-activated slag mixed with PG can be considered for in the environmental of high temperatures. Thus, the inclusion of PG in the matrix of alkali activated binders increases the possibility of reuse of this waste.

Keywords
Alkali activated binders, Phosphogypsum, Slag, Biomass bottom ash.

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Influence of aggregates on the properties and microstructure of alkali-activated slag with fine milled fibres

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Abstract

Alkaline activation is a very active and rapidly developing area of research on alternative binders. The application of alkaline activated binders is very diverse: in transportation, industry, agriculture, housing, etc. However, it differs from an ordinary Portland cement binder in its properties and production characteristics. This study deals with the production of alkali-activated binder but also the influence of various fillers on the properties of the obtained composite. The same research aims to influence the structure of the final composite by using an unusual and difficult-to-recycle waste - glass wool. This additive is expected to influence the microstructure of the composite material and improve its mechanical properties.

In this study, ground slag, aluminium hydroxide and alkaline sodium activator, glass wool waste reinforcing filler, along with sand or metal waste fillers, are used to produce alkaline activated composite (AAC). In this compound, activated alkaline slag is used as a binder. Aluminium hydroxide was additionally used to activate the binder. The addition of aluminium hydroxide strongly affects the reaction kinetics and structural evolution of the solid phases formed in the alkaline silicate activated binders. The role of Al(OH)3 in activated binder mixtures is closely related to the availability of Al in the system, as it controls the concentrations of secondary products, such as zeolites [1].

Glass wool was used in the composite as a microstructure reinforcement element. Glass wool is used in various industries and construction as an insulating material, but at the end of its life cycle, the material loses its properties and becomes glass wool residues. There is no established recycling method for these residues, and they usually end up in landfills, where they cause high costs and pollute the environment. However, the chemical composition and amorphous content of glass wool are similar to those of pozzolanic cementitious additives [2].

In the technology of ship production and repair, production waste is generated, which consists of metal and anti-corrosion coating dust. Industrial metal waste is generated during the process of technological metal cleaning of this dust. Their utilisation is problematic, therefore, ways of cheaper and more efficient utilization of these wastes more efficiently and cheaper are being sought [3]. One of the possible solutions is the use of this waste in the production of alkali-activated concrete.

The compressive strength of the cured AAC was evaluated after 7 and after 28 days. A ToniTechnik 2020 hydraulic press was used to perform the test. The compressive strength of the specimens was determined according to EN 196-1:2005. To obtain a more accurate result, each case was made in triplicate. The mineral composition of the starting materials was carried out using powder X-ray diffraction analysis. The chemical composition of the starting materials was evaluated by XRF analysis. Microstructural investigation of the starting materials and the cured AAC was carried out using a high-resolution scanning electron microscope ZEISS EVO MA10.

In the alkaline activation of AAC, aluminium hydroxide was additionally added to improve the structure of the slag by creating better bonds and a denser structure of the cured sample. The samples were cured at room temperature and no additional curing agent was used. Compared to studies conducted studies, the compressive strength was found to be slightly better.

When glass wool is added to an AAC system, the microstructure of the concrete changes due to the altered properties of the concrete. Unlike previous studies, this study used a different mixing method, mixing raw glass wool with dry ground slag. The slag particles slowly and minimally break the glass wool into individual fibres that do not agglomerate and disperse. After high-resolution scanning electron microscope analysis of all samples, glass wool fibres are clearly visible when the surface of the samples is magnified x20 times.

The fibres of glass wool are dispersed and do not stick together in larger formations. The length of the fibers ranges from 100-500μm. The binding material adheres to the fibers, and new growths are formed next to them. As a result, it can be stated that the additional mechanical insertion of glass wool fibres into the AAC structure improves the microstructure and mechanical properties of the samples.

During the research, two types of composite fillers were used: 0/2 fine sand and metal waste dust. These fillers were selected to compare their influence on the properties of the cured specimen. The binder/filler percentage compositions were 75/25, 50/50, and 25/75, respectively. And when comparing the mechanical properties of the samples, the lower compressive strength of the control samples with sand filler was observed compared to the samples with metal waste dust.

Keywords: Alkali aktivated material, metallurgical slag, glass wool waste, microstructural reinforcement, metal waste aggregate

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Dependence of properties of alkali-activated biomass fly ash on different types of fine aggregates

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Abstract

One of the measures to reduce CO_2 emissions in the European strategy can be the reuse of biomass fly ash in the field of construction materials. In Lithuania it is predicted that 156,000 t of ash and slag will be produced in Lithuania (the proportion of wood ash is not given) [1]. The same source states that the ash will be used for road construction. However, although their use is presented, additional requirements are placed on their use, due to the amount of heavy metals and their leachability [2]. One of the possible solutions to this problem is alkali-activated concrete. Alkali-activated concrete is characterized by immobilization of heavy metals, which are chemically bound. Other waste can be used in the production of such concrete, but there is not enough research in this area yet.

Although alkali-activated concrete from wood fly ash has not been extensively studied, some researchers have tried to use wood ash for alkali-activated concrete. One such researcher is Cheah Chee Ban et al [3], a study was conducted on F-type coal ash and wood ash with high calcium content. The compressive strength after 28 days was determined, from 7.8 to 1.8 MPa depending on the amount of wood fly ash. Silva et al. [4] conducted experiments with wood fly ash and glass dust. The compressive strength after 14 days without glass dust was between 3.69 and 2.85 MPa. The addition of glass dust increased the compressive strength ranging from 7.2 to 16.6 MPa. Teker Ercan et al [5] used ground granulated blast furnace slag and wood fly ash (three types: unground, ground for 10 min and 20 min). The best compressive strength results (62 MPa - after 7 days and 72 MPa - after 28 days) were obtained using sodium silicate activator and wood fly ash which was ground for 10 min. Compare the obtained results with the results of the control samples (100% slag) - no significant influence of wood fly ash was observed. H.S. Hassan et al. [6] mixed diatomite and wood biomass ash with wood ash added from 7.7 to 43% by weight of diatomite. The best result was obtained with the addition of 21.5% wood ash, the compressive strength after 28 days was about 50 MPa. F. Ates et al. [7] mixed F-type fly ash with wood biomass fly ash (unheated and heated at 800 ^oC for up to 3 hours). F-type fly ash was replaced by 10%, 30% and 50% wood fly ash. The maximum compressive strength after 7 days of the samples that were not heat treated was approximately 46 MPa with 30% wood fly ash, while the strength of the control sample is approximately 33MPa. A. C. S. Bezerra et al [8] tested fly ash with high calcium content and iron ore tailings. The highest compressive strength after 28 days (~4.8 MPa) was obtained with a ratio of SiO_2 to Na_2O of 1.55.

Biomass (wood) fly ash (BFA), bottom ash (BBA) produced from a bubbling fluidized bed (reactor temperature ~800 ^oC) in a power plant, quartz sand (QS) and iron waste (IW) were used in this study. The biomass bottom ash was sieved through a 1.25 mm sieve. NaOH is used to activate biomass fly ash, the mass ratio (NaOH\BFA) is 0.15. The fly ash was mixed with fine aggregates in mass ratios: 1:0.5, 1:1, 1:2, 1:3 (BFA: aggregates). First, fly ash was mixed with aggregates, then the mixture was mixed NaOH solution. The formed samples were placed in sealed plastic bags, and cured in ambient conditions for the first 24 hours. For the next 24 hours, the samples are heated at a temperature of 60 ^oC, then cured in ambient conditions for up to 28 days. The compressive test of the samples was performed after 7 and 28 days.

The compression test after 7 and 28 days revealed:

- Samples after 7 days with quartz sand (5.0 MPa) and iron waste (5.7 MPa) were weaker by 15% or more. The compressive strength of samples with bottom ash (6.1 MPa) after 7 days was lower only by 8.9% (mass ratio BFA 1:0.5 BBA);
- Samples after 28 days with quartz sand (6.2MPa) and iron were only weaker (6.4MPa) by 7.4% and 4.5%. The composition of samples with bottom ash improved the compressive strength after 28 days (7.1 MPa), the compressive strength increases by ~6.0% (mass ratio BFA 1:0.5 BBA);
- Optimal biomass fly ash to aggregate ratios obtained: BFA 1:0.5 BBA, BFA 1:1 QS and BFA 1:1 IW.

Keywords
Alkali-activated binder, Alkali-activated concrete, wood fly ash, quartz sand fine aggregate, iron waste fine aggregate.

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Comparative study of alkali activated systems made of ceramic brick and metakaolin waste under different curing conditions.

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Abstract

Nowadays, a fast life pace is leading to a high intensity urbanization, which intensifies the expansion of the construction sector. Severe urbanization is leading to the higher demand of concrete, the world's most consumed building material. The increased need for concrete has a negative environmental impact. The production of concrete requires a significant number of non-renewable resources and the production of the essential component of concrete (Ordinary Portland cement) results in large amounts of CO_2 emissions (1 t of cement emits about 0.95 t of CO_2) [1]. One way to enhance the sustainability of the construction sector is to replace ordinary cementitious materials with alkali activated materials (AAM's). AAM's are produced with the activation of aluminosilicate precursors and alkaline solution leading to a strong hardened material with OPC like mechanical properties [2]. The best part of AAM's is that new building materials can be made completely out of industrial waste and by-products.

It is widely known that the rate of a chemical reaction is increased with the temperature, and an adequate curing is necessary to achieve improved mechanical properties in alkali activated systems. The aim of the study is to investigate the difference between two curing conditions (ambient temperature and thermal curing) on the mechanical properties of AAM. This study was conducted according to the scheme shown in Figure 1.

Fig. 2. The course of the investigation.

The alkali-activated binder (AAB) compositions include two aluminosilicate precursors: ceramic brick and metakaolin waste (ratios of 100/0, 80/20, 70/30, 60/40, 50/50, 40/60, 30/70, 20/80 and 0/100), with calcium – phosphogypsum (5% wt. of precursor) and sodium hydroxide. According to Roboyo et al. [3] thermal curing can have a huge positive impact on AAM mechanical properties since increased curing temperatures accelerates the reaction kinetics geopolymerization and favors the dissolution of the active species. Also, Komnitsas et al. [4] advises to select curing conditions very carefully, because too high temperature (>150◦C) and

time (>48 h) creates a risk of contractions and microcracks in the matrix by rapid dehydroxylation in the geopolymer gel.
Study results are like above mentioned authors [3-5] and have proved that thermal curing at 60◦C for 24 hours intensifies the formations of new compounds, leading to a final compressive strength increase and especially in the early period. Although, the disadvantage of thermal curing is that it needs more energy, making the curing method less environmentally friendly. Nevertheless, the selected precursors show very decent results when curing at ambient temperature. Thus, building materials with low need of high final and early compressive strength can be cured without any additional energy resources, making them more eco-friendly.

Keywords
Alkali activated binder, ceramic brick waste, metakaolin waste, sodium hydroxide, compressive strength.

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Additive Manufacturing: 3D Printing of Concrete with a Low Environmental Impact

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Abstract

This comprehensive research explored the development and evaluation of concrete mix designs tailored for 3D concrete printing (3DCP) applications. The study is grounded in a fundamental goal to reduce environmental impact by employing locally sourced materials and innovative approaches to construction. This was done by replacing the cement content with fine globigerina limestone powder. Replacement of the coralline limestone sand with recycled globigerina limestone sand was also assessed to confirm the viability of 3D concrete printing with such a mix design. A prototype Concrete 3D Printing Frame System, designed and constructed by the Construction Materials Research Group, University of Malta was used for the 3D printing of concrete elements in this study.

This research was conducted in three primary phases, each contributing essential insights into the concrete behaviour and its performance in the context of 3D printing.

In the initial phase, trial mixes were developed based on different constituent materials. The fresh and hardened properties were determined in order to assess the effects of different constituent materials on the concrete mix. It was observed that the reduction in cement content, coupled with the introduction of globigerina limestone powders and sands, in general led to a decrease in compressive and flexural strength. Furthermore, substituting coralline limestone sand with globigerina limestone sand resulted in notably weaker material. With the addition of different additives such as Superplasticizers (SP), Viscosity Modifying Agents (VMA) and Accelerators (Acc.), a significant change in the concrete fresh properties was reported. This stage paved the way for the second stage intended to optimise the concrete mix design.

The second phase was intended to evaluate the suitability of concrete mixes for 3DCP. Various properties, such as extrudability, workability, shape retention, and open time, were assessed. The 3DCP mix was optimised for extrusion, assessing the pressure required to overcome the material's static yield stress. Following the optimisation process, larger elements were then printed using the 3D prototype printer. An iterative process was employed addressing the key variables including the mix design and optimised fresh properties, the print speed and other key factors to achieve the required 3D printed elements.

The third phase examined the hardened properties of printed samples, focusing on core density, compression strength, and porosity. The density of 3D printed extruded samples was found to be lower than laboratory samples, attributed to increased air volume resulting from the absence of vibration during extrusion. Consequently, compression strength was lower in the extruded samples. A higher porosity was also observed, underlining the presence of numerous voids.

In conclusion, the study successfully achieved its aim by developing concrete mix designs that are both eco-friendly and suitable for 3DCP. While cement content reductions were associated with decreased strength, the mixes remained robust for 3D printing purposes. The research establishes a foundation for future studies, including the determination of yield stress range, the impact of different cement types, and waste limestone powders on the mix design, effect of water absorption of limestone powders, effects of hardening accelerators, and embodied carbon assessments. Moreover, it underscores the potential of 3DCP based on waste limestone as a sustainable construction method, reducing the carbon footprint associated with traditional construction practices.

Keywords
3D concrete printing; concrete mix design; low environmental impact; low carbon, globigerina limestone, waste recycling

Principles of circular economy in building construction

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Abstract

Today, society is focused to meet Sustainable Development Goals (SDG) [1]. 17 goals were defined that are "vital for a recovery that leads to greener, more inclusive economies and stronger, more resilient societies. This contribution primarily deals with the "SDG 12 Ensure sustainable consumption and production patterns', which is focused to implementation of the 10-year framework of Programmes on Sustainable Consumption and production patterns. The objectives relevant to the construction industry are as follows:

- 12.1 to achieve by 2030 the sustainable management and efficient use of natural resources,
- 12.2 substantially reduce waste generation through prevention, reduction, recycling, and reuse;
- 12.6 encourages companies to adopt sustainable practices and integrate sustainability information into their reporting cycle.

This could be achieved through solving two main issues that exist nowadays:

The first is related to the past – there are many buildings at the end of the life cycle. These buildings were built at a time when long lifespan was not considered, and these buildings no longer meet the requirements for today. For these reasons, in the context of a circular economy, the main goal is to find a way to maximize reuse or recycle materials from these buildings.

The main goals related to the first one in which the SDG 12 could be achieved through:

- Optimization of the demolition and recycling process, which enables the reuse and recycling of secondary materials produced during the construction and demolition process.
- Motivation of producers to return the materials separated during construction and demolition process, which will be possible to achieve by developing of separating and logistic system, and also showing possible environmental and economic savings.
- Optimization of the use of recycled materials by finding possibilities for applications for secondary raw materials whose use is not allowed by standards such as recycled masonry aggregate and fine recycled aggregate.
- Finding answers to doubts to products with secondary raw materials related to its durability, life span and life cycle.

The second one is in connection with the future – there is still the traditional approach to structural design, which is focused only on the required parameters, which correspond to standards requirements. Evaluation of the performance quality is limited to the construction stage or to the construction guarantee period. However, the new conceptual approach to structural design is an integrated life cycle design (ILCD), which represents a multiparametric

design of structures. The main objective of the ILCD is optimized performance parameters from a wide spectrum of sustainability criteria throughout the entire life cycle and its extension.

The new fundamental imperatives of circularity are not only dealing with the reuse and recycling of waste materials, but also with thinking about the future in architecture engineering. The following principles should be considered:

- Design for Disassembly – the main focus of the principles outlined here relates to the end of the life cycle of a building, with a focus on the assemblies and the systems in the built environment. These facilities should be designed to allow dismantling at the end of life or during renovation, with the possibility of reusing their components for other purposes and potentially other facilities.
- Design for Adaptability and Flexibility – Flexible design allows the building to adapt over time and meet the changing needs of users. The ability to adjust and change design elements ensures that the building remains functional and up-to-date even as operational requirements change, preventing it from becoming obsolete or irrelevant.
- Design for Durability – In the context of the built environment, sustainability implies designing buildings and building components that are built to last and can stand the test of time. The principles outlined here apply to all phases of the building lifecycle, as they minimize repairs from the first design phases and continue the life of the building.

Keywords
Circular Economy Principles, Building Construction, Recycled Materials, Construction and Demolition Waste.

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1. THE 17 GOALS | Sustainable Development.

Alkali Activated Materials based on Waste.

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Abstract

The 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 increase in construction activity is leading to higher demands for construction products, with increased pressures on natural resource extraction including the extraction of aggregate and cement for the production of concrete and concrete products. In particular there is a large demand for concrete blocks in the construction industry. Cement as a binder in concrete, has a high embodied energy with negative impacts on the environment.

The ReCON project (Large Volume Waste Recycling for Low-Impact High-Performance Concrete) 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 new product consists of a low-impact high-performance concrete, an eco-construction product based on waste excavation material. The innovation lies in the transformation of the waste into a high-performance construction product, without the use of cement as a binder. The new product is produced through a new technological process based on a production methodology consisting of key steps and resulting in premium quality products for the construction industry. The final product is strong, stable and durable for construction applications.

The new product can effectively provide for the increasing demand for construction products. It can be presented in the form of building blocks, cladding panels or in other geometries and forms of high-performance construction products. The new product is based largely on waste, resulting in a reduction in consumption of raw materials and less waste disposed, and lower environmental impact. The new technology effectively transforms large quantities of waste into a resource, a low-impact high-performance material.

The Effect of High-Volume Dosages of Lignite Fly Ash on the Properties of Concrete

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Abstract

As a result of the increasing energy demand and crises, fossil energy carriers are currently being exploited, so the amount of fly ash produced as a by-product in a pulverized coal-fired thermal power plant increases and accumulates yearly. The use and utilization of fly ash will remain important in the upcoming decades objective. However, it should be noted that the properties of these fly ash can be different: chemical and physical properties in terms of their elemental composition, pozzolanic activity, and other properties. Depending on its chemical and physical characteristics, it is possible to use fly ash as a partial or even complete replacement for traditional Portland cement.

This research involved locally available secondary raw material (industrial by-products, such as fly ash, slag, etc.), creating eco-concrete. The secondary raw material we selected was fly ash from the Mátra Power Plant (Visonta area, Hungary) from burning lignite powder. Our goal was to study the high-dosage application of fly ash in concrete. The fly ash dosages (25, 50 and 75 V% cement replacement), two different specific surfaces of fly ash and the effects of various additives were studied. In addition to being used in conventional, cement-bound concrete, we also started testing the cement-free (100 V% cement replacement) alkali-activated concrete in related research.

During the research, ten concrete recipes were examined by substituting Portland cement in varying volume ratios (25 V%, 50 V%, 75 V%). The Portland cement concrete, without any substitution, was used as a reference. In the concrete mixtures, the test parameters were the aggregate framework, binder volume and water content. Significant initial strength reduction of concrete occurred due to the limited pozzolanic reaction in the high-dosage (75 V%) substituted binder. We tried to enhance the hardened properties of concrete by using various additional materials and property-improving technologies, e.g., mechanically activating (grinding) the ash.

Experimental investigation on the properties of cement mortars with the addition of recycled inert asbestos

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Abstract
This work reports the results of an ongoing experimental campaign, aimed at evaluating the behaviour of concrete produced with the addition of Inertized Asbeton (AS-I). This study aims to minimize the environmental impact, to meet the requirements of the UN Agenda 2030 [1]. The green economy is based on energy saving, the use of renewable energy, and recyclable products that produce minimal waste with production lines that reduce carbon emissions. These specifications force researchers, economists, and politicians to find materials that verify these conditions and therefore to study new mixtures with a low environmental impact [2].

It is well known that cement has a high environmental impact, it has been estimated that the extracted ion of raw materials for its production and firing represents approximately 8% of global CO_2 emissions and 12 to 15% of global industrial energy consumption [3,4].

The objective of this experimental program is precisely to reuse inert asbestos cement as an addition within mortars or concretes to allow waste from an unwanted stigmatized material to be recovered and to reduce the quantity of cement.
For this reason, samples of cement mortar were prepared with Portland cement type CEM I 32.5 (CEM) and normalized aggregate, with the addition of different percentages of inert asbestos (10%, 15%, and 20% AS I) to reduce the percentage of the quantity of cement inside the mix.

Table 1. Porosity and Median Pore Radius (volume).

Type of Specimen	Porosity [%]	Median Pore Radius Volume [μm]	Apparent (skeletal) Density [g/mL]
100% Cement	14.70	0.12	2.52
100% AS I	53.15	0.27	2.03
90% Cement + 10% AS-I	19.34	0.13	2.49
85% Cement + 15% AS-I	22.04	0.14	2.47
80% Cement + 20% AS-I	22.37	0.15	2.46

All samples have been evaluated and analyzed from a physical and mechanical point of view, through dynamic elastic modulus according to standard (EN 14146), tests of the static elastic modulus (ISO 6784), compression and flexion tests (EN 1015-11), and non-destructive ultrasonic wave propagation tests were also carried out (EN 12504-4). Porosity and density analysis tests (MIP) were carried out to highlight the role of inert asbestos on the physical behavior and mechanical of this new concrete mix.

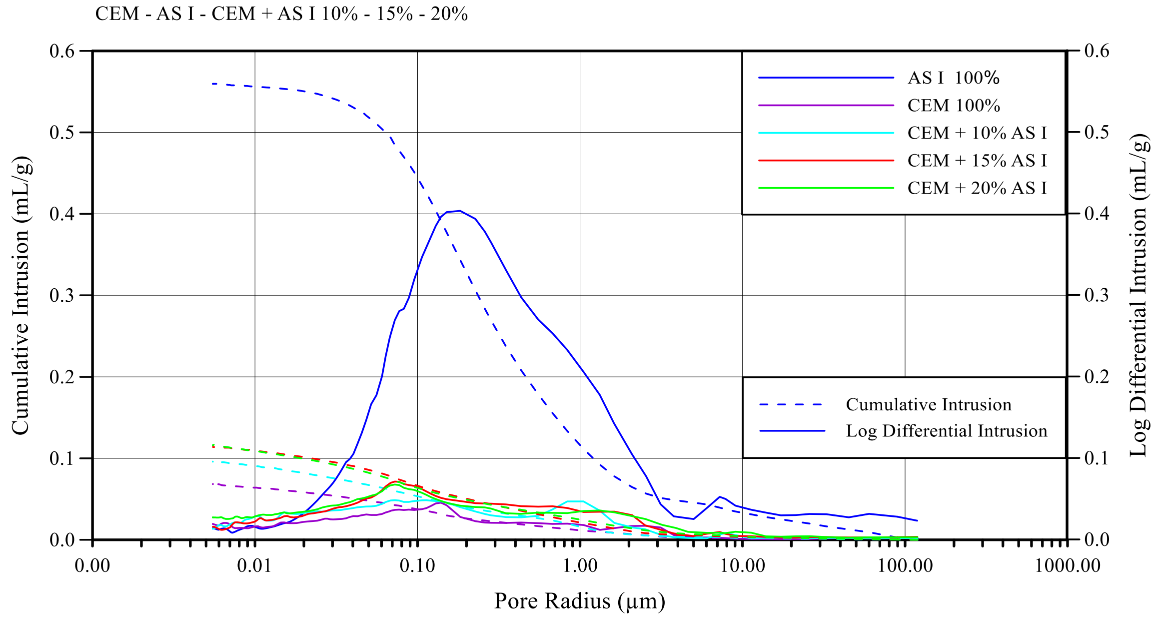

Fig. 3. MIP - Cumulative volume distribution and differential volume of different samples with Cement (CEM), Inertized Asbetos (AS-I), and CEM and different percentages of AS-I (10%, 15%, 20%).

From the first results, it appears that after treatment, asbestos partially maintains its physical characteristics, giving the mixture with cement-insulating properties and greater lightness, opening up new futures for the material and reducing carbon emissions.

Keywords
Circular economy, Inertized Asbeton, Green mortar, physical and mechanical behaviour.

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An EU policy to promote CDW recycling as concrete aggregates

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Abstract

In traditional linear economic models for the construction sector, raw material consumption and Construction and Demolition Waste (CDW) generation are two sides of the same coin. The circular economy addresses this issue by shaping the production cycle to close it, bringing the two sides together. Concrete is the most widely used building material in the world and plays a key role in construction and will continue to be used during the green transition to produce safe and durable buildings and infrastructure. At the same time, concrete is also responsible of the share of 56.2% CDW produced in EU.

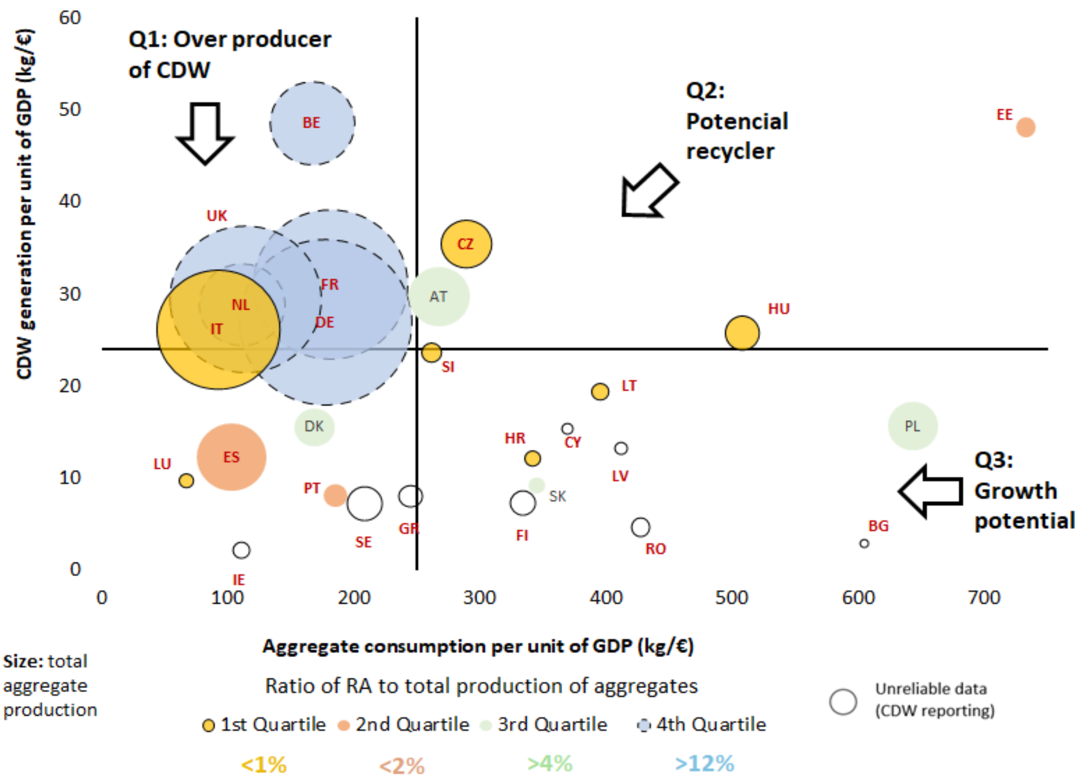

Fig. 4. Quadrants for classification of EU27 and the UK by potential for CDW recovery as RA [1].

The amount of Natural Aggregates (NA) consumed and CDW produced per unit of GDP measure this impact. In summary, in the EU27 in 2020, 250 kg of aggregates were consumed to produce € 1,00 of GDP, while 23 kg of CDW (mineral fraction) were generated at the same time. These indicators divide Member States (MS) into four quadrants: those that consume more or less aggregates per unit of GDP and generate more or less CDW than the average. This

can be the basis for developing specific policies so that MS, regardless of their situation, can use the circular economy to reduce or contain waste generation while reducing the use of natural resources.
Quadrant 1 contains the CDW overproducers: the five largest economies in the EU27 (with the exception of Spain). In absolute terms, these countries are both the top producers of aggregates and the top generators of CDW. Compared to their GDP, they have a significant amount of CDW with a below-average production of aggregates. These are either countries where access to natural aggregates is scarce (the NL and BE) or where aggregates are affordable and abundant (FR, DE and IT).
Quadrant 2 identifies the Potential Recyclers: the four countries (AT, CZ, HU and EE) are average producers of CDW in absolute terms and Poland could belong to this group due to its absolute values. They are characterised by a high relative production of CDW and a high relative consumption of NA. This means that there is a large potential supply of RA and, at the same time, a large demand for aggregates for construction. These MS have the greatest potential for increased recycling of CDW, as they currently do not fully exploit the potential use of RA.
Quadrant 3 comprises nine countries (Poland assimilated to the former group) with high Growth Potential, five of which were reported as having unreliable data on CDW generation and treatment [2]. What they all have in common is a below-average generation of CDW. They consume more aggregates than the average, while in absolute terms their production of NA is low. The implementation of the circular economy in the construction sector in these countries would significantly increase the recycling of CDW, allowing the economy to keep the consumption of primary raw materials low.
The seven Frugal countries in the quadrant 4 both generated less CDW and produced less aggregates than the average. Three out seven are reported as having unreliable data [2]. Countries in this quadrant meet the target of low consumption of aggregates and low generation of CDW. However, with the exception of Denmark, all countries with reliable data underperform in terms of CDW treatment.
The Science for Policy Report [1] presents a comprehensive policy analysis to implement the CE in the concrete sector, and presents 10+1 measures for each contexts.

Keywords
CDW, Recycled Aggregates, Circular Economy, EU Policy.

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Bio-Based Fibres for use in cement composite materials

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Abstract

Concrete is one of the most widely utilized construction material due to its versatility and is employed in various applications in the construction sector. It has several beneficial characteristics including high compressive strength, fire resistance and durability. However, concrete also has its drawbacks such as poor tensile strength, brittleness and weak crack resistance. Thus, fibre reinforcements are introduced in cement-based materials to improve its toughness and ductility and to control cracks [1].

The invasive Agave plant has been rapidly spreading in the Maltese islands, displacing native species and potentially harming local structures and biodiversity. Extensive removal efforts have been undertaken, but the disposal of these alien species through incineration poses a significant environmental challenge [2]. To mitigate this issue, it is crucial to utilize this by-product in an innovative and sustainable way that contributes to a more circular and sustainable economy.

This study investigates the potential use of Agave Sisalana fibres in self-compacting concrete (SCC) and their impact on its fresh properties, early age characteristics and hardened properties of concrete. The influence of different fibre lengths, specifically 15mm, 25mm and 35mm, with various fibre volume percentages of 0.25%, 0.50% and 1%, were considered as indicated in Table 1. To evaluate the performance of the concrete specimens, experimental tests were conducted to assess the compressive, flexural, tensile and shrinkage behaviour.

Table 2. Different mix variable considered

Mix	Fibre Length (mm)	Volume Fraction (%)
1	-	-
2	15 mm	0.25%
3	25 mm	0.25%
4	35 mm	0.25%
5	15 mm	0.50%
6	25 mm	0.50%
7	35 mm	0.50%
8	15 mm	1%

The findings obtained from the testing of the fresh properties indicated that the introduction of fibres in the concrete mix reduced its self-compacting characteristics. This reduction was primarily observed in the passing ability of the mix, with instances of clogging resulting in loss of performance. However, despite this expected decrease in performance, the SCC still maintained certain flow characteristics.

For the early age characteristics, both concrete and mortar were subjected to controlled environmental conditions. The concrete specimens were placed in an environmental chamber, while the mortar panels were exposed to directed wind from high-velocity fans. The results indicated that the addition of Agave fibres contributed to a decrease in plastic shrinkage cracks widths and delayed crack development. Additionally, the restrained concrete ring test also demonstrated higher strains exerted on the steel ring with an increase in fibre percentage.

Regarding the mechanical properties, the addition of fibres resulted in a decrease in density, ultrasonic pulse velocity and compressive strength of the concrete. However, it also led to an increase in the flexural peak load and tensile splitting strength. The research demonstrated the potential exploitation of Agave sisalana fibres to enhance the properties of concrete, including the rheological properties, the early-stage characteristics and mechanical properties.

Keywords
Self-compacting concrete, fibre reinforced concrete, Agave sisalana fibres

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Recycled Bio-polymer feather Fibre Reinforcement for Cement-Based Materials

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Abstract

The poultry production industry is an economically important agriculture-based activity worldwide. The industry leads to the production of significant waste including large quantities of feathers with challenges associated with disposal. Keratin-rich feather fibre can be used in an innovative way as reinforcement in cement-based construction materials such as low-impact concrete addressing the principles of circular economy. Feathers have been utilised in different ways; as whole fibres, hand-cut rachis, ground fibres and a combination of both feather fibres and ground feathers. Feather fibre cement-based materials have been used for the creation of feather-board as a low-cost material which can be utilised for non-structural applications [1]. Investigations in feather fibre cement-based materials also refer to the effect on mechanical characteristics, setting time and hydration characteristics [2, 3].

The RECP Research Project objective is to reutilise the biomaterial which would have otherwise reach its end-of-life stage. This study investigates the potential use of feather fibres in cement-based materials including self-compacting concrete and the effect on the fresh properties, early age characteristics and hardened properties including mechanical and durability properties.

An operating procedure was developed including washing and shredding, to transform the feathers into a product ready for inclusion in concrete. The effects of different fibre lengths with varying fibre volume percentages were considered in the concrete mixes.

An experimental investigation was conducted to assess the fresh properties, with reference to empirical tests and rheology. The introduction of fibres in the concrete mix led to a reduction in the workability and self-compacting characteristics. The early-stage characteristics of concrete were assessed using an environment chamber in a controlled environment. The fibre concrete was observed to influence the plastic shrinkage cracking. The restraining concrete ring tests confirmed the influence of the fibres on the strains exerted on the steel ring with varying percentage of fibres in the mix. The addition of fibres also influenced the concrete density, ultrasonic pulse velocity, compressive strength, flexural peak load and tensile splitting strength. The durability of feather-fibre concrete was assessed with reference to permeable porosity and permeability and chloride ion penetration. The inclusion of feathers as fibre reinforcement in concrete was found to have different effects on the fresh, early-stage and hardened properties of concrete, depending on fibre length and percentage volume fraction.

A life cycle analysis was also conducted to assess the environmental benefits and impacts in relation to the exploitation of feathers in concrete industrial applications.

The research confirmed the potential of the exploitation of waste feather fibres as reinforcement in concrete supporting circularity in the agricultural and construction sectors. The study demonstrated the potential use of feather fibres in cement-based materials, in self-compacting

concrete, through the assessment of the fresh properties, early-age characteristics, and hardened mechanical and durability properties. The research project demonstrated the effective reutilization of the biomaterial that would have otherwise reached its end-of-life stage.

Keywords
Chicken feather fibre, natural fibre, fibre reinforced concrete, biomaterials, biopolymers, keratin waste fibres, low-impact concrete, sustainable building materials.

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The dynamics of Piezoelectric Micromachined Ultrasonic Transducer arrays embedded in reinforced concrete.

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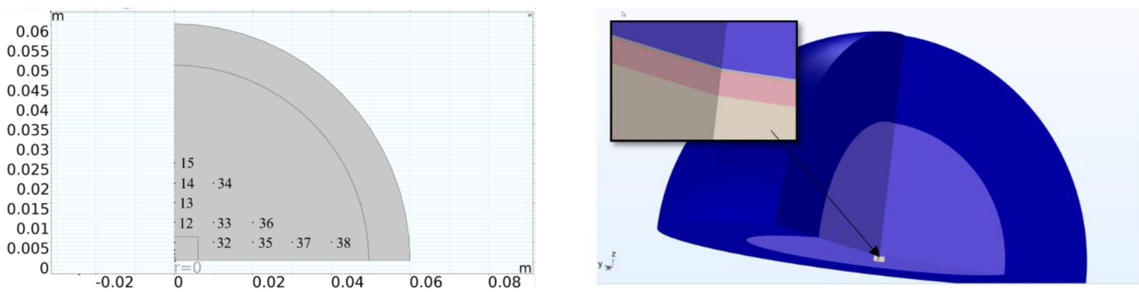
Abstract

Sensors embedded in a Reinforced Concrete (RC) structure create a Structural Health Monitoring (SHM) system which could monitor issues detrimental to the health of RC. This paper will explore the possibility of using an array of Piezoelectric Micromachined Ultrasonic Transducers (PMUTs) as a means of transmitting data between such embedded sensors. Due to the acoustic properties of RC, the frequency of operation of such a system would ideally be around to or less than 100 kHz [1]. This paper outlines the work conducted through Finite Element Modelling (FEM) using COMSOL™ and verified through experimental processes to predict the pressures which can be potentially created by a PMUT array.

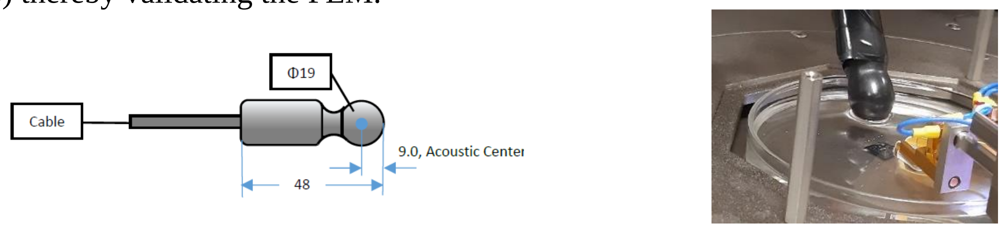
The first step of the FEM process was the building of a 2 D axisymmetric model shown in Fig.1. to calculate the coupling fluid pressure which would be induced by one PMUT.



(a) (b)

Fig. 1. A 2D axisymmetric model showing (a) the coupling fluid hemisphere overlying the PMUT and its cavity situated at point r=0 (b) the 3D rendition of the model with the PMUT and cavity underlying the coupling fluid area.

In this FEM a 700 μm diameter PMUT produced a pressure of 167.48 Pa at the point marked 38 in Fig.1.(a). This was verified through an experimental process using the hydrophone setup shown in Fig.2., where the maximum pressure of 170 Pa was measured at the same point (point 38) thereby validating the FEM.



(a) (b)

Fig.2. (a) The dimensions of the BII-7001 hydrophone and (b) deployment of the hydrophone in the coupling fluid on the probed die.

Next the FEM capsule shown in Fig.3. was designed, using low density polyethylene (red). The FEM capsule had a 10 mm diameter with a 1mm wall thickness. Blue and yellow show the low density (isopropanol) and high density (glycerin) coupling fluids respectively. Inside the finite element capsule a 13 x 13 PMUT array was set up.

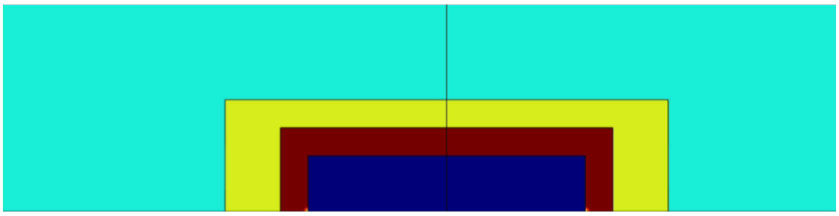
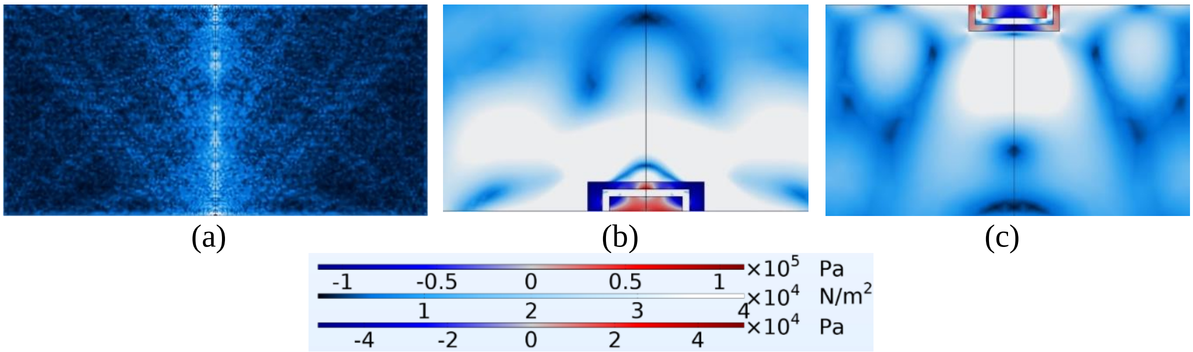


Fig. 3. Section through a capsule containing a proposed array.

Fig.4. shows the results of the final FEM with 1.2×10^5 Pa created in the transmitting capsule and 20×10^3 Pa being induced inside a receiving capsule, situated 1 m away in RC. This value was high enough to be detected by the receiving PMUTs thus confirming that an ultrasonic communication distance of 1m through RC at a frequency of 90 kHz is feasible through the use of microscale devices.



Upper bar- Transmitting capsule pressure, middle bar – Solid Misses, lower bar pressure in reciving capsule.

Fig. 4. Finite element modelling results showing (a) solid misses stress levels within the concrete structure (b) the total acoustic pressure in the transmitting capsule and (c) the total acoustic pressure within the receiving capsule.

Keywords
Piezoelectric Micromachined Ultrasonic Transducers (PMUT), ultrasonic, concrete, Structural Health Monitoring (SHM), pressure.

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Investigations on composite mineral binders for self-compacting modified soil

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Abstract

The aim of this scientific work is to investigate the properties of self-compacting soil (SCS) with a modified composite mineral binder suitable for different types of soil.

Portland cement CEM I 42.5R was chosen as the basis for the development of self-compacting modified soil (SCMS) composite mineral binder using materials available on the Lithuanian market. The composite material obtained on the basis of this binder was also compared with the physical and technical properties of Carbofill E, a specialized binder used for soil reprocessing.

In order for the developed binder to ensure water impermeability, or to have lower strength in order to produce a re-excavated soil with this binder, the influence of the mineral additive Bentonite-(S11) and the superplasticizer Sika® ViscoCrete D-190 on the properties of cement stone made from normal thickness paste was tested [1, 2]. The obtained results were also compared with the properties of the specialized binder Carbofill E.

When studying the mechanical properties of the composite binder with Bentonite (S11), mixtures were prepared with 5%, 10%, 15%, 20% of this mineral additive, replacing part of the base Portland cement CEM I 42.5R with it.

Comparing the results of compressive strength after 28 days of curing with Bentonite (S11) content, a clear tendency of compressive strength decrease was obtained, but the workability and stability of the SSG mixture improved [3. 4]. The average compressive strength of cement stone prepared from Portland cement CEM I 42.5R without Bentonite (S11) addition was 83.8 MPa, while cement stone prepared from Portland cement CEM I 42.5R with 10% Bentonite (S11) addition decreased by 28% (up to 60.3 MPa), while that of cement stone prepared from Portland cement CEM I 42.5R with 20% Bentonite (S11) additive decreased as much as 67.8% (up to 27.0 MPa). However, when designing a composite binder, the more important parameter is not the compressive strength of the cement stone, which will still provide sufficient binder strength (mechanically resistant in the case of SCMS soil), albeit less, but the ability to ensure water impermeability (water impermeable in the case of SCMS soil). And in the case of re-excavated SCMS soil, the lower compressive strength of cement stone will only be an advantage.

The dependence of the compressive strength of the obtained cement stone with 0.8% superplasticizer Sika® ViscoCrete D-190 on the hardening time and the amount of Bentonite (S11) additive used was also evaluated. After 28 days of curing, the average compressive strength of the cement stone of the composite binder made of Portland cement CEM I 42.5R with 0.8% superplasticizer Sika® ViscoCrete D-190 and 5% Bentonite (S11) additive was not lower (83.7 MPa) than the control (80.8 MPa). When evaluating the compressive strength results after 2 and 7 days of curing under laboratory conditions, it can be seen that with the

increase in the amount of Bentonite (S11) additive (from 0% to 10%), the compressive strength of cement stone had a tendency to decrease.
During the scanning microscopy studies, surface texture changes were visible when a portion of Portland cement CEM I 42.5R was replaced with different amounts of Bentonite-(S11) additive. As the amount of Bentonite (S11) additive increased (from 5% to 20%), the surface of the air pores formed in the cement stone of the composite binder changed from uniformly roughened to uniformly smooth and then clearly layered surface. This clearly showed that the addition of Bentonite (S11) influences cement stone compounds and their structural derivatives. By changing the amount of Bentonite (S11) additive, the physical and mechanical properties of the resulting cement stone can also be changed.
We conclude that it is proposed to prepare the SCMS composite binder from Portland cement CEM I 42.5R with Bentonite (S11) (from 5 to 10% of the cement mass) mineral additive. To ensure the workability parameters of the prepared binder, it is recommended to use superplasticizer Sika® ViscoCrete D-190 at 0.8 ... 0.9% of the amount of Portland cement.

Keywords
self-compacting soil, self-compacting modified soil, composite mineral binder, re-excavated SCMS.

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Concrete admixture based on Intelligent Cluster System simplifies the transition to low-clinker concrete

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Abstract

With a global consumption of 13.5 billion m^3, concrete is by far the most widely used man-made material; it is also responsible for 8% of the global CO_2 emissions. Due to growing population and urbanization, the production of concrete will further increase, along with its impact on the environment. Measures to reduce the embodied carbon of concrete are therefore paramount to the achievement of the challenging targets posed by the Green Deal.

The production of clinker by burning natural raw materials such as limestone, clay, and marl at very high temperatures, is responsible for most of the CO_2 emissions of cement and, consequently, of concrete. Although clinker generally accounts for only about 10% of the volume of concrete, in fact, it is responsible for up to 90% of the CO_2 embodied in concrete.
Lowering the percentage of clinker in concrete is the necessary measure to make construction more sustainable in the future. This can be achieved mainly in three ways: by introducing a new cement with reduced clinker content, by reducing the dosage of the cement in use or by replacing a portion of cement with supplementary cementitious materials (SCMs) or limestone. However, the change of concrete mix design to reduce clinker most often leads to negative effect on concrete performance: loss of workability, worsening of the rheology and reduction of mechanical strengths are the main undesirable outcomes that frequently occur. The boundary conditions of low-clinker concrete are narrower, and robustness of the production is reduced. To tackle these issues, very often the dosages of cement and water are increased, thereby diluting, or even erasing the effect in terms of CO_2 reduction, besides increasing costs and posing risks of lowered quality.

A new range of superplasticizers, based on the innovative technology Intelligent Cluster System (ICS) addresses the performance gaps and limitations associated with low-clinker concrete, that conventional superplasticizers cannot overcome.

The superior rheology of MasterCO$_2$re in comparison to conventional superplasticizers is the real driver of the transformation, as it allows to further reduce the water content in concrete, without any negative impact on pumpability, placing and finishing of concrete. The robustness of concrete is highly improved, so that corrective actions like increase of water and cement, can be avoided. Master Builders Solutions, as a leading supplier of concrete admixtures, aims to help the construction industry meet the current sustainability challenges and to simplify the production of low-clinker concrete without compromising on quality and efficiency.

An Appraisal of a Historic Reinforced Concrete Structure: The Naval Reservoir

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Abstract

This study is based on the Historic Naval Reservoir built in Hal Luqa between 1905 and 1909. The objective of the study was to define an assessment methodology for the heritage structure and conduct a detailed appraisal of the structure and its components. The appraisal was based on scientific methods, including the appraisal of the structure through inspection, scanning, and photogrammetry; non-invasive assessment through non-destructive tests on the structure and materials assessment based on experiments on extracted samples to define the properties of materials in the structure.

The Naval Reservoir was constructed at the beginning of the 20th century. It consists of a vast underground space excavated in Globigerina limestone, with masonry block columns resting on concrete bases, supporting spandrel parabolic arches, which in turn support a thin reinforced concrete shell structure. The Naval Reservoir has been associated with the drydocks in the Grand Harbour, Malta. It is considered to be the first reinforced concrete structure, at least of such scale, in the Maltese islands.

The different structural elements at the Naval Reservoir exhibit different defects, in particular the reinforced concrete roof elements, including spalling of concrete and cracking in different shell elements. In addition, its water-retaining properties have been impaired over the years. The study aims to identify the degradation mechanisms on different elements, based on historic documentation and inspection of the structure, which were further supported through photogrammetry, non-destructive tests (NDT), and materials analysis on extracted samples. The NDTs included Cover Meter, Schmidt Hammer, Ultrasonic Tomography, Ground Penetrating Radar, and Resistivity Meter. The non-invasive techniques allowed for a definition of the characteristics of the structure, including the location and cover of the reinforcement and the potential for corrosion. The Ultrasonic Tomography and Ground Penetrating Radar were used to assess various defects of the structure associated with the presence of voids and reinforcement in the concrete. The addition the Thermal Camera, was exploited to scan and assess the surfaces of the structural elements of the structure and delamination. The reinforced concrete roof shell exhibits degradation ins specific areas, with spalled concrete and exposed reinforcement. The concrete spandrel type arches did not show significant damages.

The assessment of the extracted core samples from different strategic locations and different elements, was necessary to determine the material properties. The extracted cores indicated the use of a coralline limestone aggregate in the reinforced concrete shell structure, and globigerina limestone aggregate in the spandrel arches supporting the shell roof structure. Different tests were conducted on the material to define the mechanical and durability properties, including the compressive strength and core density, the depth of Carbonation, Vacuum Saturation Porosity, Chloride ion content with depth, Ultrasonic Pulse velocity and Resistivity.

The appraisal of the structure, based on the photogrammetry and scanning, the non destructive tests and the materials analysis, forms part of a more comprehensive assessment of the structure and informs additional studies leading to its restoration and exploitation as an asset for the storage of water. The assessment methodology developed based on data collection and experimental results for the different masonry, concrete and reinforced concrete structural elements, supports the conservation efforts. The findings shed light on the state of the structure and the possible causes of degradation.

The appraisal conducted was reviewed with reference to the Getty Framework: Conservation Principles for Concrete of Cultural Significance, the Burra Charter and the Declaration of San Antonio, among other key sources, towards conservation of the heritage structure. The Naval Reservoir can be effectively restored through a conservation approach and exploited as an asset for the storage of water. An outline conservation strategy is proposed with reference to restoration of key elements based on advanced repair techniques.

Keywords
Historic Concrete, Structural Appraisal, Mapping of Defects, Non-Destructive Testing, Material Assessment, Analysis of Degradation, Conservation

Nonlinear Mechanical Analysis of a Historical Blockwork Breakwater: the case of St. Elmo in Malta

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Abstract

The structural analysis of a historical blockwork breakwater has been investigated by creating a bidimensional finite element model in Abaqus software. The structure under consideration is the St. Elmo Breakwater, one of the two breakwaters protecting the Grand Harbour, the main harbour of Malta. The breakwater was constructed with massive precast concrete blocks, cast-in-place concrete elements and limestone blocks. Reference was made to the original historic drawings of the breakwater to construct a finite element model of the structure, taking into account its general geometry and also block construction.

The exact geometry and the materials used in the structure were defined in the first instance, in order to perform an implicit static linear analysis and then an explicit quasi-static nonlinear analysis. Several models have been thereafter implemented in order to take into account the static and dynamic nonlinear aspects that may affect the overall structural response.

Nonlinearities are introduced by modeling a frictional interaction between the interfaces of the elements and by applying the Concrete Damage Plasticity Theory [1]. Using the provisions of Eurocode 2, the constitutive law of historical concrete was evaluated to calibrate the parameters of the Concrete Damage Plasticity model and to represent the possible crack formation and propagation. The external actions considered are specifically, the self-weight of the structure and the water pressure on both sides of the structure. Initially, the sea action is considered to be only hydrostatic, but then the impact force of the colliding waves is also considered and modeled as a static equivalent load, with reference to the Goda formula [2].

The aim of the study is to verify the structural response and the possible formation and propagation of cracks due to the impact of the design wave with a return period of 200 years.

Keywords

Blockwork Breakwater, Concrete Historic Structure, Frictional Interfaces, Damage Mechanics, Concrete Damage Plasticity.

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Assessment of the Structural Health Monitoring of a Historic Reinforced Concrete Water Tower

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Abstract

Degradation of Reinforced Concrete structures exposed to aggressive environment is of major concern in the construction industry. The work presented refers to the thorough assessment of a structure, the Water Tower at the Malta Civil Abattoir, exposed to an aggressive marine environment and its restoration using advanced materials, restoration technologies and monitoring systems. This Water Tower was constructed in the 1930s and is located in the Grand Harbour, close to the coast. It suffered severe degradation due to a coastal exposure. The restoration required a comprehensive approach covering different critical and important stages. The restoration of the structure and use as a Water Tank required an appreciation of the historic structure and relies also on the use of advanced materials which can address the requirements of the structure. The project included the following stages:

- Advanced appraisal of an industrial heritage structural for conservation, through materials testing, numerical structural modelling and scenario testing to optimise repair and strengthening interventions.
- Development and then the application of advanced ultra-high performance materials applied for the first time, including ultra-high performance self-healing nano-additive based concrete and carbon textile reinforced high performance concrete for the strengthening of the structure.
- Development of new techniques for restoration of concrete heritage structures including electro-chemical chloride extraction, re-alkalisation of reinforced concrete, epoxy injection and polymer concrete patch repair with corrosion inhibitors, re-integration of the structure, and an advanced sensor network system for monitoring over time.

New materials and technologies were developed to address the challenging conservation process. The innovative materials and technologies promote the long-term behaviour in the structure. These materials were developed for their use in the strengthening of the different elements in the structure; they consist primarily in the following high performance concrete systems:

- Ultra high performance – high durability fibre reinforced concrete with ultra-high strength self-healing and self-compacting propertied, applied to the columns
- Textile reinforced concrete with carbon textile / resin reinforcement with high strength and self-healing properties, applied to the tank.

The long-term monitoring approach is based on an advanced structural health and Durability monitoring system together with environmental monitoring. The system is based on 150 sensors embedded in the structure, the data collection and processing in real time, to monitor

the long-term performance of the structure and also its performance during normal operation whilst in service for the storage of water. The advanced Sensor Network System included a Durability Monitoring system based on Galvanic, Resistivity and Embedded Reference Electrode sensors; Structural Health Monitoring based on strain gauges and accelerometers; Environmental Monitoring with a weather station which captures data on weather conditions including solar radiation, temperature and precipitation. The sensors are located in different structural elements and parts of the structure for overall monitoring. In addition, a microtremor ambient noise investigation was carried out before, during and after restoration, with monitoring of the tank also when empty and when full of water.

Data from the sensors related to monitoring is collected through the installation of a Data Acquisition System. Although the number of channels on this DAQ is limited, a number of multiplexers were used to expand this number of channels. Typically, these take readings once every few minutes for the durability and strain gauges, while continuous readings are taken for the accelerometers. The data gathered from the structural health and durability sensors is intended to understand the performance of the restored water tower over time with respect to different environmental conditions and actions during operation. The monitoring system was used during the validation process when the tank, having a capacity of 400 cubic m of water was filled in with water gradually and then emptied. The performance of the structure during a seismic event was also assessed with reference to the structural health monitoring sensor system. In addition, the performance of different sensors in different parts of the structure and different orientations was analysed.

The analysing of the data generated through the structural health monitoring system (strain gauges and accelerometers) indicated that the systems is capable of assessing the performance as anticipated at the design stage of the monitoring system. In addition, the sensor monitoring system indicated that the structure performs as per structural design considerations, when considering its behaviour at different stages, before and during filing in, with the tank full of water and on emptying the tank. The water tower's performance over time is monitored through the durability sensor system intended to monitor degradation and assess the effectiveness of the restoration and the durability of the restoration and strengthening methods employed. The monitoring of the Reinforced Concrete Water Tower, allows for real time assessment of performance of the structure, supporting the conservation strategy.

Keywords
Structural Health Monitoring, Durability Monitoring, Restoration, Sensor Network Systems, Concrete Conservation

Military Heritage: Documentary Attitudes Towards Pillboxes in Malta

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Abstract

The construction of pillboxes in Malta gained momentum in 1938 as a crucial component of a comprehensive defence strategy, aimed to thwart the potential invasion by Italian forces. Initially, these pillboxes were erected in the susceptible northern region of the island of Malta, but as time progressed, they were dispersed in the most vulnerable areas of the island and located at critical and other strategically important positions to function as defensive strongholds. By the conclusion of the war, it is estimated that approximately 200 pillboxes had been erected.

Pillboxes played an indispensable role in Malta's defence strategy during World War II. The majority of these compact and fortified structures were constructed using reinforced concrete, although a few were made from stone while their sizes and shapes varied. The choice of concrete as the primary building material was particularly advantageous due to its robustness and durability. Additionally concrete has the ability to withstand shell impacts and absorb the energy generated by explosives. Furthermore, it is resistant to fire, cost-effective, and relatively easy to construct even in remote or challenging environments.

Although pillboxes serve as tangible reminders of Malta's wartime experiences and the resilience of its people, today they stand as silent and forgotten witnesses from bygone eras. However, their significance can extend beyond their historical and architectural value. In fact, these blockhouses can offer intriguing opportunities for studying the evolution of warfare, military strategy, military architecture, composite materials and the interaction of humans between themselves and their environment. After the end of World War II, these structures underwent various fates, including demolition, abandonment, leasing to third parties or occupied illegally by squatters. Nearly eighty (80) years on this situation has not changed much.

Keeping this objective in focus, the primary goal of this study was to assess the public's opinions and attitudes on pillboxes, as well as to investigate their significance as part of the national heritage. Moreover, the study aimed to explore how the rationale for their adaptive and sustainable reuse can contribute to their preservation and conservation without diminishing their significance.

In addition to conducting a comprehensive review of pertinent literature, this study encompassed three qualitative research components. These included individual interviews with an expert panel, two online surveys: one designed to assess participants' viewpoints and, perceptions regarding pillboxes as heritage assets, and the other employing an image-based questionnaire to evaluate various pillboxes through a visual approach, aimed at eliciting spontaneous and emotional reactions.

Furthermore, a non-invasive evaluation study was conducted in collaboration with students at the Faculty for the Built Environment at the University of Malta (Degradation of Building Materials Study Unit). This assessment focused on several pillboxes located along the coastline of the Inwadar Park area, in Marsaskala, Malta. Its purpose was to gauge the degree of material degradation and the overall condition of these structures. Such an assessment plays a pivotal role in the conservation approach for pillboxes.

While it might be presumptuous to assert that this research offers conclusive and unambiguous insights into the public's views and sentiments regarding pillboxes, especially considering that it appears that this is the first study on the topic, it does lay a solid foundation for forthcoming research endeavours.

Keywords
Pillboxes, military heritage, concrete heritage, attitudes, resue

Sustainability by Historical Concrete Structures

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Abstract
One of the major factors in order to provide sustainability of concrete structures is to increase service life, i.e. to have improved durability. Some of the concrete structures already gave good examples of adequate material selection, construction methods, and maintenance strategies. Fig. 1 indicates the Centennial Hall in Wroclaw, which received a Unesco World Heritage listing in 2006. The Centennial Hall was opened in 1913. Fig. 2 indicates a very interesting detail of the Petőfi Theatre in Veszprém, which was opened in 1908 and seems to be the first theatre constructed in reinforced concrete. This concrete cantilever supports the balcony.

Fig. 1: Centennial Hall, Wroclaw (1913)

Fig. 2: Concrete cantilever supporting the balconies in Petőfi Theatre in Veszprem (1908)

In both cases of Figs. 1 and 2, maintenance work was carried out together with some strengthening work, but refurbishment was not needed to keep the serviceability of the structure.

Extending the service life
The more complex case is whenever the service is extended by refurbishment of the structure. This is only possible if the following conditions are met.

- The owner of the building is ready to take the extra cost of the refurbishment.
- A reasonable way of refurbishment can be developed technically and economically.
- The aspects of aesthetics after refurbishment are met.
- Enough safety and serviceability exist after refurbishment.

In all these cases, sustainability is provided by the extended service life of the building, i.e. the period of time for the use is extended considerably.

Strategy of refurbishment

- We have to avoid a considerable increase in self-weight.
- We should not forget that refurbishment results in the removal of some of the internally applied materials.
- Corrosion protection for steel and, in some cases, for concrete is required.
- Fire resistance can be required.

Figure 3 indicates a large industrial building that was constructed in 1930 and refurbished in 2019 for an office building. This building required considerable maintenance and strengthening [1] work, but finally, the building was able to serve office purposes without being demolished.

Fig. 3: Industrial building (1930) in Budapest refurbished to offices

Keywords

Historical Concrete Structures, Service Life, Extended Service Life, Refurbishment, Strengthening

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The advances of fib TG6.3 on sustainability performance assessment of precast concrete structures

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Abstract

Sustainable construction practices have emerged as key across the industry. The stakeholders involved in the sector are shifting their practices towards the adoption of strategies that allow for a carbon footprint minimization, resource conservation, energy efficiency increase, and overall enhancement of the resilience of the built environment.

Within this context of sustainable construction, precast concrete structures have proven as a building technique that can offer a range of benefits in the construction process, including reduced use of materials, increased construction speed, improved quality control, increased recyclability of materials and reduced waste generation on site.

Precast concrete structures also possess inherent qualities that make them attractive for advancing sustainable construction and enhancing overall built environment sustainability (*fib*, 2003, 2018). As a result, they are increasingly adopted in diverse construction projects, including residential buildings, civil works, bridges, and industrial/commercial complexes (*fib*, 2004, 2006, 2008, 2011, 2017, 2020).

Against this background, international organizations such as International Federation for Structural Concrete (Fédération Internationale du Béton, *fib*) play a pivotal role in promoting sustainability across various industries, including construction, as is in the *fib* Model Code for Concrete Structures (2020) that has Sustainability as the reference for the design, construction, maintenance and dismantlement of concrete structures. In this context, *fib* TG 6.3 "Sustainability of Prefabrication" is involved in the evaluation of sustainability of structures with precast elements. This *fib* TG comprises experts from around the world and from different areas, and over the last years it has focused its efforts on the proposal of a methodology to assess the sustainability of precast structures.

In alignment with these global efforts, this paper presents the MIVES-based sustainability assessment approach including components and their allocated weights (Table 1). After several meetings, these components and weights were considered representative for the quantification of precast concrete sustainability.

Table 3. Components proposed by the *fib* TG6.3 for assessing sustainability performance of precast concrete component. The weight of each component in parenthesis.

Requirement	Criteria	Indicators
R1. Economic (36%)	C1. Cost (61%)	I1. Direct (61%)
		I2. Indirect (6%)
		I3. Rehabilitation (11%)
		I4. Dismantling (21%)
	C2. Time (39%)	I5. Production & Assembly (100%)
R2. Environmental (39%)	C3. Emissions (55%)	I6. Emissions of CO_2-eq (100%)
	C4. Energy (19%)	I7. Energy consumption (100%)
	C5. Materials (26%)	I8. Index of Efficiency (100%)
R3. Social (25%)	C6. Safety (60%)	I9. Index of Risk (100%)
	C7. Third parties' affectations (40%)	I10. Social Benefits (55%)
		I11. Disturbances in construction (45%)

Keywords
Precast concrete, sustainability, MIVES, *fib* TG6.3, multi-criteria

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Building better, for longer, with less: Holistic lessons learnt from a lustrum long research on Ultra High Performance Concrete at Politecnico di Milano DICA: from H2020 ReSHEALience to Italy PNRR MUSA

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Abstract

The recently concluded Horizon 2020 project ReSHEALience, "Rethinking coastal defence and green Energy Service infrastructures through enHancEd durAbility high-performance fiber reinforced cement based materials", has developed a new conceptual design approach for concrete structures exposed to challenging structural scenarios, including extremely aggressive environmental conditions. Ultrahigh Durability Concretes (UHDC), based on Ultra High Performance Fibre Reinforced Concretes (UHPFRC) and Textile Reinforced Concretes (TRC) incorporating nano additives to enhance functionalities, have been developed and validated, under mechanical and aggressive scenarios in lab and on-site. The approach combines, in a holistic life cycle thinking framework, higher and longer lasting performance with enhanced structural functionality and high value aesthetic requirements. The signature of high resilience material concept developed and validated in the project - "branded" as UHDC - also features the possibility of engineering the structural performance over time through its self-healing capacity, i.e. the ability of the material to self-repair without external intervention but thanks to its suitably designed composition cracks and defects. Thanks to this innovative conceptual design approach for structural engineering, concretes are no longer regarded as providers of passive protection only, whose degradation over time has to be delayed as much as possible, but become active players in shaping their own performance as a function of the requirement in the operating scenario while retaining functionality and aesthetics. The conceptual design approach, suitably "nestled" into a life cycle thinking framework, represents a key driver for advanced materials innovation uptake in concrete construction industry and is going to be brought to the final level for practitioner applications in the project MUSA – Multilayered Urban Sustainability Action, funded by the European Union – NextGenerationEU, under the National Recovery and Resilience Plan (NRRP) Mission 4 Component 2 Investment Line 1.5: Strenghtening of research structures and creation of R&D "innovation ecosystems", set up of "territorial leaders in R&D". The overall performance assessment must no longer rely on the merely misleading concepts of material unit volume cost and environmental impact at its time of generation. Contrarily, it has to be framed appropriately into a structural functional unit context all along its service life. The project results have demonstrated that up to 70% less amount of material can be used to achieve the same or higher structural and durability performance, with maintenance from five to ten times less frequent all along the reference service life period.

This represents a breakthrough innovation in the approach of concrete construction industry to the use of advanced cement based materials, overcoming the current situation where Ultra High Performance Concretes are very often promoted only through their extremely high compressive strength, whereas their higher durability is simply accepted as a bonus but has hardly been quantified as true benefit in design, construction, maintenance and use stage of buildings and structures.

This new concept has been demonstrated by the project consortium in six full-scale pilot applications serving a broad portfolio of challenging societal needs, also implementing a synergic contribution towards the EU decarbonisation objectives. They include: two tanks, for water (TRL6) and mud (TRL7) collection, in a geothermal power plant in Italy; a floating raft for mussel farming (TRL7) and a floater of an offshore wind tower in Spain (TRL6) (Mediterranean sea); a floating pontoon in Ireland (TRL6) (Atlantic west coast) and the retrofitting of a reinforced concrete heritage structure in Malta (TRL7). The paper will summarize the main findings of the project with a specific focus on the real scale applications and their design validation.

Keywords
UHPC, durability-based design, sustainability, life cycle analysis, life cycle cost

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The Behaviour of Plain Unconfined Concrete Under Cyclic Compression Loading

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Abstract

Although concrete is one of the most utilized construction materials worldwide, the mechanical properties when suffering damage are still being understood due to its complex non-linear and random behaviour. The complexity is increased when cyclic loading is involved, such as in the case of seismic considerations.

Uniaxial behaviour of concrete has been experimentally investigated comprehensively. Insight on cyclic loading effects with analytical considerations is provided [8]. Most publications concern peak stresses, and monotonic considerations only [7]. More recent publications refer to FEM aspects [9]. If design codes are considered, EN1992-1-1:2004 [4] quotes stress-strain models for plain concrete based on monotonic loading considerations and further considerations on a stress-strain model for concrete are then made in EN1998-3:2009 [6] where the Newman Model is used to incorporate confinement effects. However, accounting for cyclic considerations is then only made through the hysteretic models during Finite element analysis procedures. Such models are rarely accessible for practical purposes due to the complex structure of algorithms.

The effect of different loading regimes on mechanical properties of low and normal strength concrete are therefore investigated through a systematic experimental campaign. The testing campaign consisted in uni-axial compression tests conducted on concrete cylinders, and was auxiliary to a more extensive campaign involving quasi static tests on RC elements [1,3]. Standard concrete cylinders measuring 150mmx300mm were used. The tests were carried out according to EN12390-3 [5] and the number of samples was 144. Three different loading patterns were utilised; one consisting in monotonic loading, and another two incorporating cyclic loading. The number of cycles applied was determined through an analytical procedure [2]. Following various non-linear time-history analyses of typical reinforced concrete (RC) frame buildings for various seismic hazard scenarios, the mean number of effective response cycles for most components was estimated to be 10. The first cyclic pattern included 10 cycles at 80% of maximum monotonic strength and before the maximum strength is reached, and the other pattern included 10 cycles at 80% of maximum monotonic strength after this is reached but before the ultimate strain.

For each loading pattern, the distribution of strain at maximum stress, strain at 20% of maximum stress after this is reached, and strain at 50% of maximum stress after this is reached are statistically compared. The strain at maximum stress is confirmed as assumed in EN1992-1-1:2004 [4], to be around 0.002. The cycles before maximum did not have a considerable influence on the general behaviour of concrete in terms of strain, both for maximum and ultimate considerations. Nevertheless, cycles after the maximum have a large influence on the ultimate stain such that this has decreased. The response of RC elements is highly affected by the loading pattern. While traditional codes mostly focus on forced-based Engineering Demand

Parameters (EDP), energy and displacement-based parameters can quantify damage development more effectively. The effect of energy dissipation on the stress and stain parameters was therefore investigated.

Keywords
Cyclic Loading, Stress-Strain, Compressive strength, Plain Concrete.

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The influence of concrete mixture compaction parameters on the quality of formed concrete surface

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Abstract

Mechanical compaction of conventional concrete with poker vibrators is usually divided into two stages [1]. In the first stage (lasts 3 to 5 sec.), known as slumping, tiny air bubbles merge into larger ones, which typically remain in the lower layers of the concrete mixture. In the second stage (which lasts from 7 to 15 sec.), which removes entrapped air, air bubbles move upwards to the concrete/formwork interface and escape. Release oils of different chemical compositions prevent bonding between the hardened concrete and the formwork. Water-based release agents are determined to create fewer surface voids on the formed concrete surface than oil-based agents. Release agents must be applied in a thin film on the surface of the formwork; in the opposite case, the excessive amount of release agent causes poor formed concrete quality [2]. The paper focuses on the influence of fresh concrete compaction time when a poker vibrator is used on the appearance of surface voids on the formed concrete surface.

The conventional fresh concrete was prepared at the laboratory according to standard EN 206:2013+A2:2021 requirements. At first, the following fresh concrete properties were determined: temperature, slump, density and air content. Concrete test specimens were cast in plastic moulds coated by two types of release agents (RA) based on mineral oils (RA-MO) and water-soluble emulsion (RA-WSE). At the same time, the moulds were coated using an ordinary amount of RA and an excessive amount of RA. The fresh concrete was compacted using a poker vibrator; the compaction duration for each specimen was the following: 2, 4, 6, 8, 10, 12, 14 and 16 seconds. The surface finish quality was evaluated regarding the concrete surface void ratio (SVR, %) and was calculated as the total void area ratio to the total area of the analysed concrete [3]. In addition, surface voids of diameter ranging from 0 to 2 mm, from 2 to 5 mm, from 5 to 10 mm, and from 10 to 15 mm were investigated. The total area of the analysed concrete surface for each specimen was 82000 mm^2. The formed concrete surface was photographed, and all taken photos were investigated using an open-source image processing program, ImageJ.

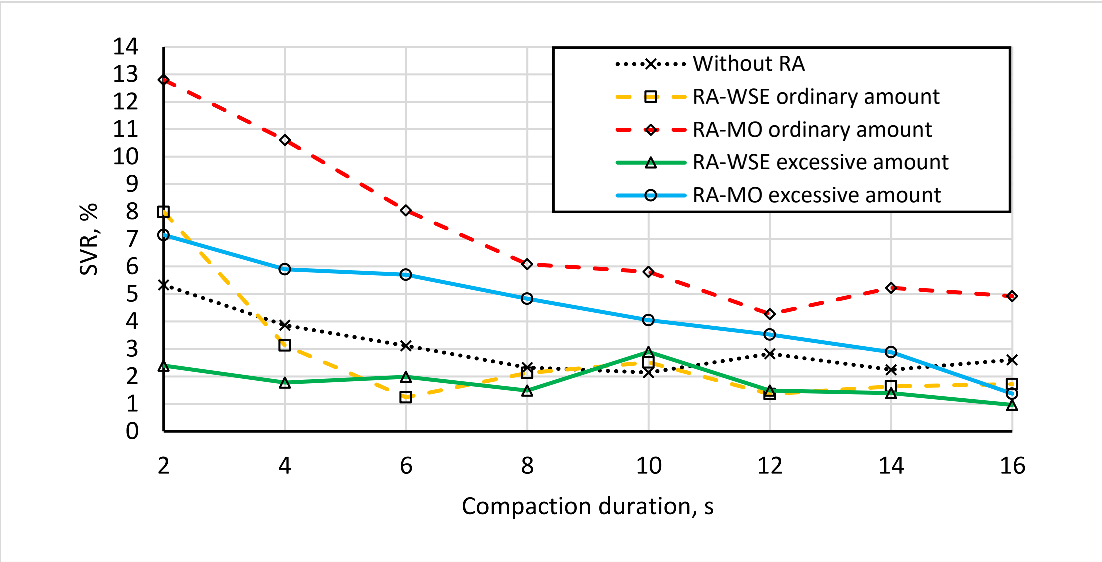

Fig. 5. Variation of SVR index depending on compaction duration while ordinary and excess amount of RA is applied on the mould.

The results reveal that the compaction duration of fresh concrete and the type of RA impacts the void surface ratio. Fig. 1 shows that considering the influence of the compaction duration on the quality of the formed concrete surface, the area occupied by the surface voids decreases pretty evenly with the increase of the compaction duration of the fresh mixture from 2 to 16 s. It was observed that after coating the moulds with an ordinary amount of RA-MO, the amount of surface voids and the area they occupied increased by about two times compared to the RA-WSE. Consequently, when using an RA-MO, air bubbles are more challenging to escape from the mixture/formwork interface during compaction; they connect into larger surface voids than RA-WSE. Higher consistency concrete mixes (with segregation signs) while an excessive amount of RA is applied results in fewer surface voids on the analysed concrete surface. In such mixtures, the entrapped air is more readily removed during compaction at the concrete/formwork interface. Segregation can be seen on the surface of the concrete, characterised by darker and lighter spots.

Keywords
Concrete mixture, release agent, compaction duration, surface quality, surface voids ratio.

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Improvement of Concrete Durability and Strength by Water-soluble Hydrophobic Agents

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Abstract

Water-soluble hydrophobic agents (microemulsions) have the advantages of low cost and environmental friendliness compared to the use of undiluted systems of active substances. The content of the research, stated in this paper, was to investigate the interaction of water-based hydrophobic impregnations with the surface structure of concrete in order to improve durability and mechanical parameters (compressive strength). The aim was to prevent as much water evaporation as possible during concrete hydration, which resulted in the improvement of the concrete properties. Water-based hydrophobic impregnations based on silane and siloxane, epoxy resin or oil were chosen to achieve these aims. Basic tests that have been performed to compare water-based hydrophobic impregnations with solvent-based hydrophobic impregnations include absorbency, pressure water penetration depth, watertightness, concrete penetration depth, contact angle determination, and within the durability, carbonation resistance. The depth of penetration of the hydrophobization into the concrete was monitored using a digital optical microscope.

Sustainable Ternary Compositions for 3D Concrete Printing

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Abstract
3D concrete printing has been developing especially intensively in the last decade, becoming one of the promising directions in civil engineering. The most challenging task in 3D printing is the elaboration mix compositions that would have fast setting time and the necessary mechanical and rheological properties, such as printability and buildability (Fig. 1).
The aim of this study is to develop sustainable 3DP technology for gypsum-cement-pozzolanic (GCP) ternary binder composition, including building gypsum or secondary construction demolition waste gypsum (CDG), Portland cement, and pozzolanic component such as metakaolin. GCP ternary composition [1] combines the desired properties of gypsum (fast setting time) and Portland cement (high final strength). Pozzolanic component is needed to provide chemical stability for such a ternary system.

As part of this study, ternary compositions were designed and tested. The following ranges of variation of the mixture components were chosen.

- Gypsum: 40 – 70 %
- Portland cement: 0 - 50 %;
- Metakaolin: 10 – 60 %.

Fig. 6. 3D printing of ternary GCP composition.

As a result of optimization, the range of mixtures with the necessary properties for 3D printing were found. Optimized composition has a compressive strength 45 MPa in air-dry conditions and 35 MPa in wet conditions, the corresponding softening coefficient of 0.78, and water absorption of 7.7%. We are currently continuing to study the durability of this material, in particular frost resistance [2], as well as a life cycle assessment is being evaluated. Life cycle assessment of GCP compositions shows at least 1.5 times lower embodied energy and carbon dioxide emission (GWP), compared to cement mortars based on Portland cement. Using recycled gypsum obtained after recycling gypsum boards [3] will increase the environmental efficiency of new material.

Keywords
3D Concrete Printing, Ternary GCP composition, Sustainability, Life cycle.

Acknowledgment
This research is funded by the FLPP (Fundamental and Applied Research Projects) Program in Latvia under the research project lzp-2022/1-0585 "Development and characterization of sustainable gypsum-cement-pozzolanic ternary compositions for 3D printing".

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Henry Ghirlando and his work in reinforced concrete in Malta

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Abstract

My father, Henry Ghirlando (Is-Sur Kikk) was born in Tripoli, Libya in 1907 into a Maltese family that had been in Tripoli since the 1830s. In January 1930, my father graduated as Geometra from the Higher Technical Institute of Tripolitania and started working in construction in Tripoli.

In the late 1930s, the situation of the Maltese, holding British passports in an Italian Libya, became increasingly difficult and would culminate in the deportation of some 1500 Maltese to Internment camps in Italy following the outbreak of war, including my grandparents and other relatives.

So, in 1938, my father, who was told that reinforced concrete was not yet well-known in Malta, came here to work for the famous Avocato Giuseppe Pace, of Paceville. During the war, my father worked as a land surveyor in the Department of Agriculture.

In 1946, he set up Malta Reinforced Concrete, bought a site in Mriehel, where he built his office, workshops, garage, etc. We used to refer to this as Il Cantiere. In the same year, he bought the necessary equipment, including some Dodge trucks from Tripoli, and a Rosa Cometta Concrete Block making machine from Italy, thus being among the first to start producing hollow concrete blocks in Malta.

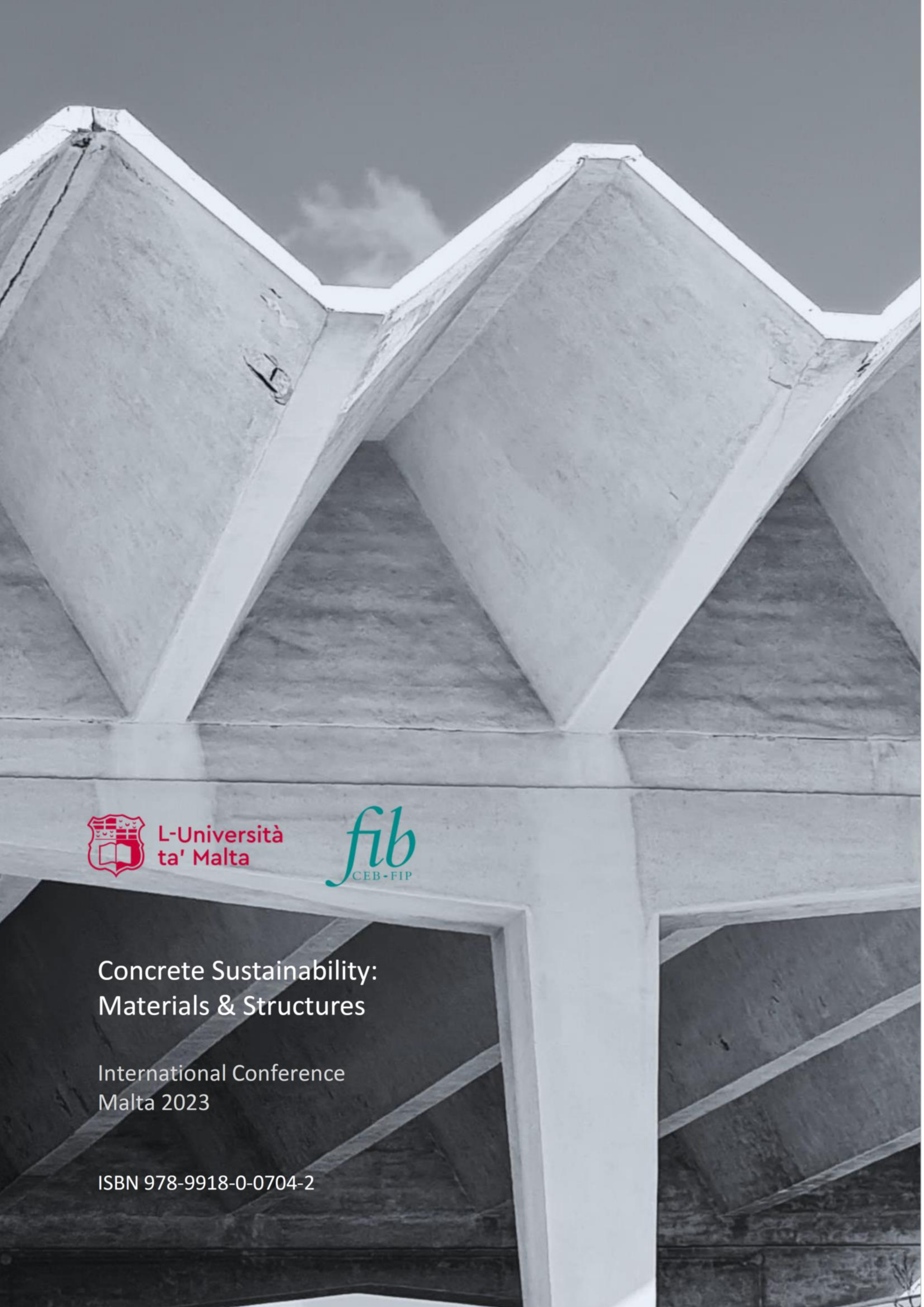
One of his first buildings was the Astra Hotel in Sliema which was demolished very recently. Since I live close by, I was able to observe the building as it was being demolished. The building is very interesting. It had a "skeleton" of reinforced concrete columns and beams. The internal walls were not load bearing and were built with narrow, hollow terracotta bricks. On the other hand, the external walls consisted of an outer layer of hollow concrete blocks filled with concrete and with steel reinforcement. This outer layer was backed by another layer of reinforced concrete cast in situ. It is interesting to point out that the outer side of the hollow concrete blocks was finished in the mould and hence did not require plastering, only pointing. I know of another two buildings that were built in the same way by my father. One is a block of flats in Sliema and another is the 1950 new wing of the School of the Sacred Heart in St. Julians.

Other works in RC that I am aware of include the clubhouse of Neptunes WPC, and wine vats in RC for a winery in Gozo. There may be other works in RC that I am not yet aware of. I am aware of other work which is not necessarily based on RC, which is why I am not mentioning it. Unfortunately, my father did not leave me much documentation, save for his books of accounts, some drawings and a number of books from the 1930s and 1950s on reinforced concrete and architecture in Italian.

My father pioneered a roofing system based on travetti which were made up of specially shaped terracotta hollow bricks held together with concrete and steel reinforcement embedded in concrete in grooves in the corners of the bricks.

One of his major works was the church of St John of the Cross of Ta' Xbiex, built in the late 1950s. Its most interesting feature from a reinforced concrete perspective are the two long beams in reinforced concrete (12.75m long) that separate the side aisles from the nave and so allow a clear view of the altar to the people sitting in the aisles.

The other major work was the NAAFI Bakery in Marsa that my father built at the start of the 1950s. This consisted of three barrel vaults. They have now been replaced by the new head office of GO plc. How my father got this work is a story worth telling. In the late 1940s, my father had tendered for the construction of a new NAAFI building in Marsa, the one that eventually became the head office of Sea Malta and was recently in the news, after part of it was demolished because of problems with its foundations but the rest was saved from demolition. My father's tender price submission was so high that he was asked to explain his costings. He explained that the nature of the site was such that he had allowed for the necessary foundations. He did not win this tender. Once completed, my father was proven right as the building immediately showed signs of subsiding. So, when the NAAFI decided to build a new bakery, they gave the work directly to my father on a Prime Cost Plus basis. As pointed out in the Times of 2nd September 1952, this building had two interesting features. One is the barrel vaults in reinforced concrete and the other, the heavy use of piles for the building's foundations. I want to conclude this short presentation by drawing your attention to the beauty of the shuttering that was set up to construct the barrel vault. I am not surprised that it looks like a boat lying upside down, since my father's master carpenter, presumably the man in the photo, was a licensed boat builder with the license to build rather large boats. But he could also build small ones, so as a small boy, I had my own little six-foot rowing boat.



Concrete Sustainability: Materials & Structures

International Conference
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ISBN 978-9918-0-0704-2