

## R2UTechnologies | Modular Systems

### Summary

The 'R2U Technologies | Modular Systems' is one of the largest projects ever funded in Portugal (94.9 M€ via PRR, the Portuguese Recovery and Resilience Plan). It envisages promoting a trend-setting change in the productive profile of the modular construction sector. The strategic goal is to promote the evolution from a labour-intensive paradigm to a new knowledge-based reality. At its core, this project is underpinned by the unwavering principles of beauty, sustainability, and inclusivity towards a future where these principles serve as the keystone of construction practices worldwide.

Herein, a subproject addressing Concrete Modular Systems is described. It gathers together the technological know-how of Vigobloco, one of the most prominent Portuguese prefabrication companies, and CIMPOR, one of two Portuguese cement producers, with the research-based knowledge of both CERIS, the largest Portuguese research unit in the Civil Engineering field, ranked as Excellent by FCT, the National Science and Technology Foundation, and LNEC, the National Laboratory of Civil Engineering.

The subproject is subdivided into fifteen sub-tasks, covering a set of key requisites/topics for the future of concrete modular systems. The architecture will be especially explored with the aim of designing spatial-type solutions for different typologies using standardised elements and modular solutions. The design strategies will be centred on 1) spatial and dimensional modularity, 2) geometry, shape and assembly of components to establish flexible, adaptable and reversible spatial solutions (Figure 1); 3) disassembly and adaptability, environmentally and economically sustainable, allowing phased construction and facilitate deconstruction/reuse by disassembly.

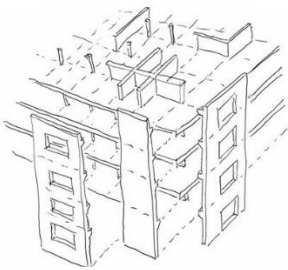


Figure 1. Vertical and horizontal assembly system.

The use of robots and automation in developing concrete precast solutions will be one of the innovations of the R2UTechnologies. The vision of Industry 5.0 elevates the digitalization concepts introduced in Industry 4.0 to a systemic level centred on people. The human operator is an integral part, and often central, to industrial processes, necessitating that robotic systems collaborate physically and cognitively with the operator. Within the scope of this project, the aim is to contribute to the modernization of Vigobloco in

this direction, that is, preserving human versatility in flexible and customized production.

Regarding the material, design and characterization of high-performance concrete (HPC) and low-carbon concrete (LCC) for modular construction is expected, aiming at developing lighter and more sustainable solutions. LCC with low clinker content and alternative, more eco-efficient admixtures (Figure 2), like recycled cement from concrete waste, calcined clay and solid waste ash, will be characterised in terms of their physical, mechanical and durability properties. Also cracking and the bond behaviour to steel and GFRP reinforcing bars will be studied.



Figure 2. Development of new LCC concrete solutions.

Connections between precast elements are fundamental to ensuring adequate structural performance, not only for current loading but also considering extreme events such as earthquakes and hurricanes. Thus, high-performance, low-cost and easy-to-apply connections will be developed and validated, supported by a comprehensive approach including experimental testing and numerical simulations. Full-scale tensile, shear (Figure 3), and out-of-plane tests will be carried out. Wall-to-wall, wall-to-foundation and wall-to-floors are some of the connections that will be studied. Detailed simulations will complement the testing campaign to optimize the solutions herein developed.

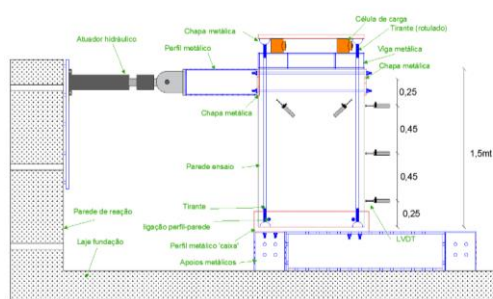


Figure 3. Shear tests on wall-to-wall connections.

The development of fully integrated prefabricated concrete wall panels is planned by defining a comprehensive pre-installation system for building hydraulic networks. With this aim, a numerical simulation and experimental testing of the hydraulic networks and the proposed assemblage and connection systems will be performed

### Project Reference

02-C05-i01.01-2022.PC644876810-00000019

### Leading Institution

DST – Domingos da Silva Teixeira S.A. (Portugal)

### Partners

VLopes – Vieira & Lopes Lda. (Portugal), ECOSTEEL S.A. (Portugal), U.Porto – Universidade do Porto (Portugal), Amorim Cork Insulation S.A. (Portugal), ARCH S.A. (Portugal), CENTITVC – Centro de Nanotecnologia e Materiais Técnicos, Funcionais e Inteligentes (Portugal), Ciência Viva – Agência Nacional para a Cultura Científica e Tecnológica (Portugal), INEGI – Instituto de Ciência e Inovação em Engenharia Mecânica e Engenharia Industrial (Portugal), INL – International Iberian Nanotechnology Laboratory (Portugal), Itecons – Instituto de Investigação e Desenvolvimento Tecnológico para a Construção, Energia, Ambiente e Sustentabilidade (Portugal), PORT-LAME – Engenharia e Madeira Lda. (Portugal), Rangel Internacional – Aérea e Marítima S.A. (Portugal), Rangel Invest – Investimentos Logísticos S.A. (Portugal), TMG – Tecidos Plásticos e Outros Revestimentos para a Indústria Automóvel S.A. (Portugal), Vigobloco – Pré Fabricados S.A. (Portugal), Building Information Modeling + S.A. (Portugal), Bysteel S.A. (Portugal), Bysteel FS S.A. (Portugal), Universidade Nova de Lisboa (Portugal), CITEVE – Centro Tecnológico das Indústrias Têxtil e do Vestuário de Portugal (Portugal), DST Solar S.A. (Portugal), DTE Instalações Especiais S.A. (Portugal), DTx – Associação Laboratório Colaborativo em Transformação Digital (Portugal), Associação Fibrenamics – Instituto de Inovação em Materiais Fibrosos e Compósitos (Portugal), Fibrauto – Fabrico de Objectos em Polyester Lda. (Portugal), IEP – Instituto Eletrotécnico Português (Portugal), Innovation Point – Investigação e Desenvolvimento S.A. (Portugal), INOVA+ – Innovation Services S.A. (Portugal), LNEC – Laboratório Nacional de Engenharia Civil I.P. (Portugal), LNEG – Laboratório Nacional de Energia E Geologia I.P. (Portugal), MCT – Metalúrgica Central da Trofa Lda. (Portugal), UMinho – Universidade do Minho (Portugal), IST – Instituto Superior Técnico (Portugal), DVM Global S.A. (Portugal), Conformetal – Indústria Transformadora de Chapas Lda. (Portugal), (continued)

to optimize both the hydraulic flow and the construction/deconstruction time.

The development of a BIM library for modular construction (Figure 4) that integrates PDTs (Product Data Templates) and DPPs (Digital Product Passports) developed specifically for modular units is expected. These DPPs enable the tracking of key information essential for product identity and sustainability, unlocking circular economy opportunities that possess the ability to benefit all stakeholders across the value chain.

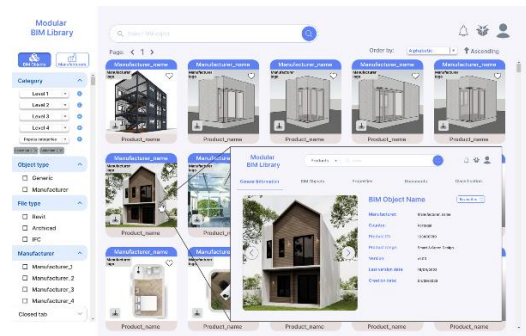


Figure 4. Example of Modular BIM library.

The thermal behaviour and energy efficiency of the fully integrated prefabricated concrete wall panels and modular building solution are expected to be developed in the project. This will include the experimental testing of the thermo-physical properties of the materials and the numerical simulation of the thermal performance of the prefabricated concrete wall system, including thermal bridge effects (Figure 5).

Moreover, energy simulation and subsequent thermal monitoring of the prototype, which will be built in the final phase of the project, are envisaged.

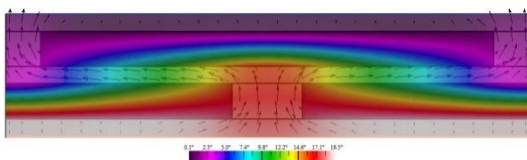


Figure 5. Example of temperature distribution and heat flux vectors in one-panel solution (top view).

Architecture design for Quality Assurance (QA) using Computer Vision systems will be assumed in this project (see Figure 6). The requirements will be defined as well as the critical parameters for monitoring and evaluation. In the first approach, computer vision will be applied to monitor geometric parameters during laboratory tests of reduced-scale models and prefabricated modular concrete structures.

The acoustic comfort will be addressed by the development of fully integrated prefabricated concrete wall panels complying with applicable acoustic performance requirements. Direct and flanking transmission of vibration and sound will be numerically and experimentally tested on full-scale prototypes, considering, when necessary,

the effect of internal vibration sources such as preinstalled hydraulic networks.

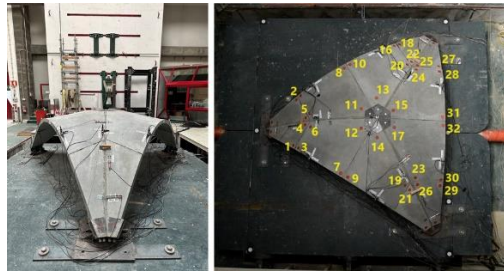


Figure 6. Architecture design for QA using computer vision systems.

DECN/C2TN team will be responsible for activities related to Indoor Air Quality (IAQ), which is essential to guarantee the health and performance of the buildings' occupants. Firstly, it will be defined the requirements of the HVAC project to guarantee the IAQ. After building the pilot, the working group will use a set of equipment and methodologies to evaluate IAQ chemical, physical and microbiological parameters, identify the factors that influence it and define improvement measures.

The fire behaviour of the concrete modular systems will be studied by coupling a comprehensive experimental study with the development of numerical tools. The former study includes thermomechanical characterization of the materials and fire resistance tests on the structural elements and their connections. In the numerical study, after validation with test results, parametric studies will allow optimisation of the elements and development of fire design recommendations.

The components and the complete solution sustainability will be assessed via Life Cycle Assessment (LCA) and Cost (LCC) methodologies. The LCA study targets to obtain an Environmental Product Declaration (EPD) per EN 15804:2012+A2:2019. Concurrently, an LCC analysis ascertains cost-competitiveness vis-à-vis market alternatives. The study culminates in the creation of innovative eco-design sheets and Circularity Passports.

Last but not least, in the case of RC buildings, the progressive collapse of the Ronan Point and the Khobar Towers is still today a reason for mistrusting the precast construction. To ensure the robustness of the conceived solution, a progressive collapse analysis will be carried out.

Besides this subproject on modular concrete systems, Itecons, due to its extensive knowledge and experience in supporting innovation and technological development, will support the development of several other materials and products carrying out their experimental validation and preparation for certification to enter international markets with the ETA and CE mark. Itecons is actively involved in 8 of the 18 technologically innovative and high-value products, services or solutions proposed by the project, namely in: High-perfor-

**Partners (continued)**

CIMPOR – Indústria de Cimentos S.A. (Portugal), UC – Universidade de Coimbra (Portugal), DISPLAY S.A. (Portugal), ABER Hydraulics S.A. (Portugal), Faria & Morouço S.A. (Portugal), Favoritanswer Consultoria em Engenharia Lda. (Portugal), SARKKIS – Robotics Lda. (Portugal), Engenharia José Figueira Lda. (Portugal), VLB Tec Unipessoal Lda. (Portugal), PIEP – Pólo de Inovação em Engenharia de Polímeros (Portugal), idMEC – Institute of Mechanical Engineering (Portugal)

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**Funding**

PRR – Plano de Recuperação e Resiliência

**Period**

2022-2025

**Total budget**

94 900 000.00€

**CERIS budget**

IST: 2 892 627.05€

Coimbra Hub: 2 076 322.51€

**Project Website**

<https://www.itecons.uc.pt/services/projects/122>

mance bathroom solutions for modular construction; Innovative wall coverings for modular construction applications; Modular Facade Systems; Minimal Window Frames; Variable Geometry Panels; Facades with laser welding; Customizable technologically advanced modular building units and 2D Hybrid modular elements.

This includes the development of innovative wall coating solutions, using new materials and solutions. To this end, Itecons is working with Amorim Cork Insulation, a world-leading cork group, to explore the use of its natural and sustainable material in innovative applications, such as exposed cladding material for façades and roofs, and is developing boards (ICB) with improved reaction to fire, to apply in high-rise buildings; it is also developing medium-density expanded cork solutions for use as passive systems in buildings, in green and evaporative solutions, contributing to the European Green Deal. The conception of these solutions imposes the definition of several alternatives for fire treatment and also assures the relevant technical aspects of functionalization (evaporative capacity and incorporation of vegetation). Besides the iterative validation of the solutions regarding their functional characteristics as hygrothermal and mechanical performance and optimization via numerical studies and small-scale tests for material and system characterization.



Figure 7. Cork panel after the SBI test.

Wood will also be applied in a modular façade system to create a carbon-neutral and more sustainable solution. The development and industrialization of hybrid wood-based products and subsystems for a new modular system will cover the three dimensions of prefabricated components - structural elements, wall and floor panels and a 3D modular construction system. This will be developed with Portilame, a company with vast experience in the production of wood-related products. The development of glued laminated timber elements will use underused local wood species and recycled wood from construction and demolition waste. Itecons will carry out the experimental characterisation for its classification with the technical performance classes required for application in structural use in buildings. This validation of the solution of Wood Frame will be carried out following EAD 340308-00-0203 "Timber Building Kits". Besides concrete and wood, the project intends to develop a new concept of modular façade systems with other

materiality - aluminium, steel or wood for the framing material - and aims to respond with effective solutions to the challenging fire safety requirements, which conventional commercial solutions are not able to effectively comply with, and to the evolution of construction principles that require slenderer and more flexible facade systems capable to absorb greater displacement of the main structure. Itecons will participate in the concept validation and experimental characterization, during the design phase and on real-scale test prototypes.

Moreover, and following the new trends of exterior cladding of building facades, with increasingly free and complex shape lines whose industry is still unable to provide an effective and sustainable response with conventional production methods, the project will tackle this limitation by developing innovative solutions focusing on new fabrication processes, new materials and new façade systems. Itecons will participate in the concept validation and experimental characterization of the design phase and on real-scale test prototypes, to validate and guarantee its performance according to European standards.



Figure 8. Aluminium minimal window during wind resistance test

Itecons will also be involved in the study and development of a set of a new minimalist window system exploring different materials – polymer composites, wood and aluminium for the frame material – and also in an innovative frameless system for large facade glass panels with minimization of out-of-plane deformation, developing the experimental validation tasks on real-scale test prototypes to determine water tightness, air permeability and wind resistance (EN 1027:2016; EN 12208:1999; EN 1026:2016; EN 12207:2016 and EN 12211:2016; EN 12210:2016). Finally, and considering the need to ensure water management and efficiency, Itecons is supporting the development of innovative solutions for assessing and classifying the water efficiency of modular bathroom construction systems. This assessment focuses on various aspects that influence water consumption, namely the use of alternative water sources, external water uses, sanitary devices, washing equipment and hot water production and distribution systems, among others, and is intended to be used to support design and decision-making, ensuring that modular systems produce an efficient and sustainable system that promotes water efficiency and circularity.