THE CHALLENGES OF CIRCULAR ARCHITECTURE IN THE INSTALLATION OF CERAMIC COVERINGS

Angel Miguel Pitarch Roig [1] [3] [4]
María José Ruá Aguilar [1] [4] **Lucia Reig Cerdá** [1] [3] [4]
Beatriz Sáez Riquelme [2] [4]

[1] **Department of Mechanical Engineering and Construction,**
[2] **Department of Industrial Systems Engineering and Design**
[3] **Ceramic classroom**
[4] **Chair in Circular Architecture**
Universitat Jaume I, Spain

1. ABSTRACT

Architecture is one of the activities that has characterised the various civilizations throughout history. Its very essence of transforming nature to create functional, habitable, and safe spaces implies significant consumption of raw materials and energy.

Current economic and social trends are increasingly aimed at respecting the environment that surrounds us, and to that end, concepts such as Sustainable Development and the Circular Economy have emerged.

The Universitat Jaume I (UJI) recently signed an agreement with the Second Vice-Presidency of the Council and Regional Department of Housing and Bioclimatic Architecture for the creation of a Chair in Circular Architecture, to be run by lecturers linked to the Bachelor's Degree in Technical Architecture and the Master's Degree in Energy Efficiency and Sustainability at UJI. It is therefore designed to be eminently technological in character.

The objectives of this Chair focus on researching and publishing possible strategies for an ecological transition in the built environment.

This paper introduces the Chair and assesses the implications that applying the concept of circular architecture may have in the field of ceramic floor and wall tiles. To that end, it compiles strategies and projects carried out by the sector and identifies the challenges faced when installing ceramic materials to meet the new requirements demanded by society in the future.

2. INTRODUCTION

Throughout history, architecture has always been one of the fundamental activities in each civilisation's development, as it makes it possible to improve people's quality of life.

That evolution has generally been based on transforming nature to make it more habitable, creating suitable spaces for the exercise of human activities.

Such transformation has had a significant impact on the planet because of its use of natural resources, energy, and water and the generation of waste. According to the European Commission (CONAMA 2018), in 2014, the construction and use of buildings in the European Union accounted for 50% of materials extracted and energy used, and 25% of the water consumed and waste generated.

As with the rest of human activities, architecture has to date been based on a linear scheme of raw material extraction, production, use, and waste disposal. In Spain, 54% of Construction Demolition Waste (CDW) in 2015 ended up as landfill.

In view of such a linear scheme, Pearce and Turner (1990) provided the first definition of the concept of "circular economy" as a closed circuit of interactions between the economy and the environment. This idea is fundamentally based on reusing the waste generated in linear systems in order to reduce the exploitation of virgin raw materials and energy and so minimise the generation of waste.

In regard to that, other concepts concerning sustainability have emerged that question the three fundamental pillars of Liberty, Equality, and Fraternity, in force since the 18th century. The evolution of those concepts in different forums and documents, such as the Millennium Goals, Sustainable Development Goals (SDG), or the 2030 Agenda, all incorporate the three dimensions of Sustainability: environmental, social and economic. Therefore, the focus is now on people, the planet and prosperity, among other aspects.

Fig 1. *The 17 SDGs: http://www.undp.org/content/undp/es/home/sustainable-development-goals.html*

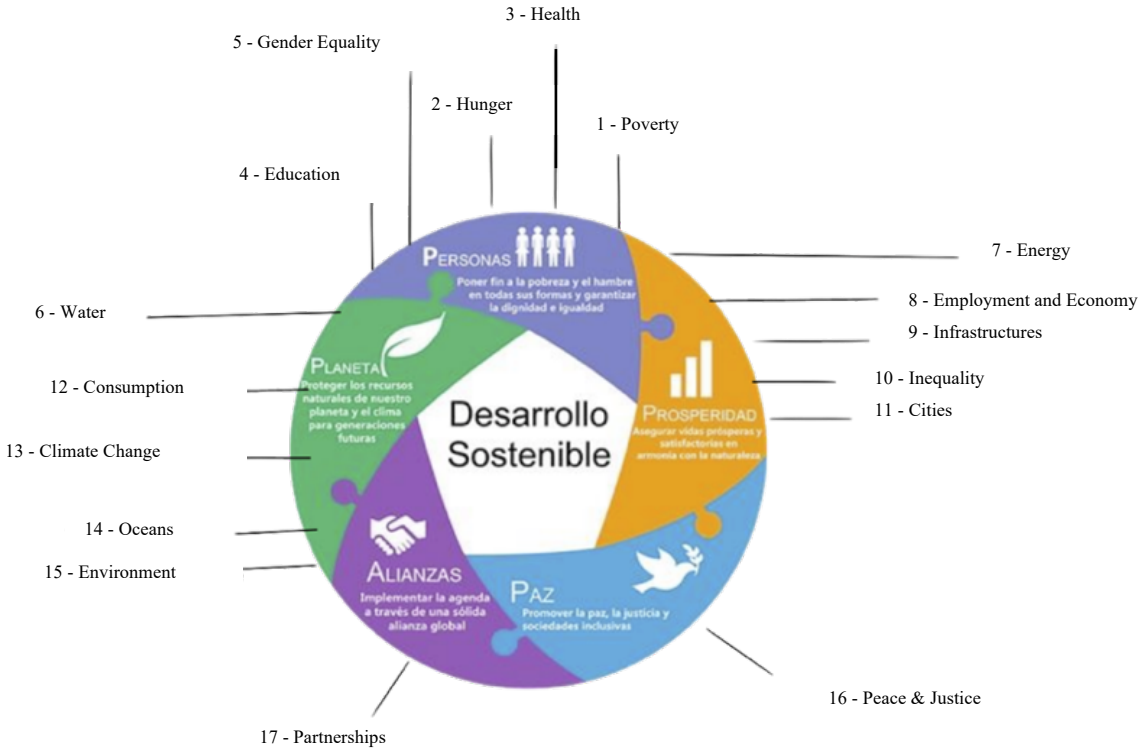

Fig 2. *The 5 areas integrated in the 17 SDGs (the 5P: Planet, People, Prosperity, Peace and Partnership) Alliance for Solidarity Foundation (2018)*

Within this framework, the application of the circular economy is progressing, with the European Union approving the first plan in 2019 called *Ecodesign* and Green Deal, followed by the new Circular Economy Action Plan in 2020. Apart from being a public initiative, the concept of sustainability and circular economy has now been adopted by the private sector, with greater relevance being given to companies' Corporate Social Responsibility.

3. THE UJI CHAIR IN CIRCULAR ARCHITECTURE

In line with such trends of environmental respect, the Second Vice-Presidency of the Council and Regional Department of Housing and Bioclimatic Architecture has promoted the creation of the Chair in Circular Architecture at Universitat Jaume I. See www.catedraarquitecturacircular.uji.es

The purpose of this Chair is to stimulate applied innovation and the transfer of knowledge to develop public policies that drive ecological transition towards a circular model in respect of architecture and the built environment.

This Chair undertakes research, teaching and dissemination activities on strategies that have the potential to boost efficient use of available resources, reduce waste generation, reuse materials, and lengthen their service life, thus creating added value, in a manner that is at all times responsible both with the environment and with people.

The Chair is run by teachers in the Departments of Mechanical Engineering and Construction and of Industrial Systems Engineering and Design, linked to the Bachelor's Degree in Technical Architecture and the Master's Degree in Energy Efficiency and Sustainability at the UJI, which makes it eminently technological in character, as it focuses on the design and installation of architectural solutions.

In this first year of its operation, various public activities such as webinars and seminars have been carried out on the contribution of architecture to the circular economy, awards for final year projects, the most outstanding end-of-master and PhD projects in this field, and technical and research reports on improvements in construction and demolition waste management, or indicators that quantify circularity in the construction sector.

4. CIRCULAR ARCHITECTURE IN THE WORLD OF CERAMIC FLOOR AND WALL TILES

In recent decades, concern for the Environment has increased significantly and, as WEF (2016) pointed out, the construction industry is crucial to the economy, society and the environment. This sector requires special attention given its significant consumption of raw materials and energy and the large volume of waste it can generate.

It is estimated that construction in Europe generates 500 million tons of waste per year, of which, according to the Spanish Association for Construction and Demolition Waste Recycling, in 2015, approximately 20.16 million tons were produced in Spain, which implies approximately 0.435 tons per inhabitant per year, of which only 40.9% has been valorised. Furthermore, according to CEDEX (2014), the main fractions in construction and demolition waste are ceramics, with approximately 54%, concrete with 12%, and stone with 5%.

Those ceramic products include structural ceramics, with items such as bricks and roof tiles, ceramic sanitaryware, and ceramic tiles, which are the three under study in this paper.

According to Baraldi (2020), world production of ceramic tiles has been growing progressively to 12.673 billion square metres in 2019. Spain is currently the no. 1 producer in Europe and the 5th largest producer in the world, with approximately 81.4% of production being exported.

According to the Spanish Ceramic Tile Manufacturers' Association (ASCER, 2020), Spanish output in 2020 amounted to 488 million square metres from 137 associated companies, with about 80% of companies and 94% of production being concentrated in the province of Castellon.

Such production volumes justify analysis from the viewpoint of sustainability and the possible application of circular economy criteria. For this purpose, three different phases in the manufacturing, use and disposal cycle of ceramic products can be distinguished.

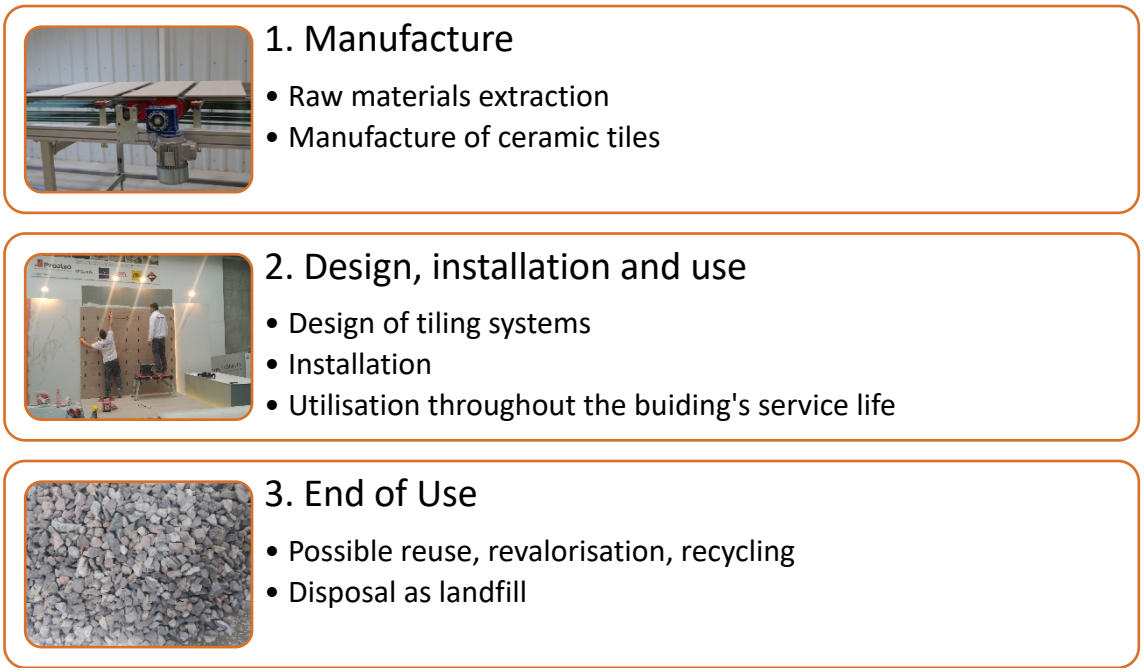

Fig 3. *Life stages of ceramic floor and wall tiles*

STAGE 1: MANUFACTURE

Undoubtedly, ceramic tile manufacture calls for significant consumption of raw materials that in some cases are locally sourced but which can generally be extracted anywhere in the world and transported by cargo ships.

Likewise, it also calls for large consumption of energy, both to transportation and to form and sinter the tiles, a process in which current technology makes significant use of natural gas.

Despite the fact that a remarkable amount of waste is generated during manufacturing, the tile-making process itself enables a large part of that waste to be reused. Thus, ASCER (2021) set the figure of 1,200,000 tons per year of non-hazardous waste (sludges, slurries, unfired and fired tile scrap) valorised in the ceramic tile manufacturing process.

The challenges in this field can thus be summed up as follows:

- Reducing natural raw materials and increasing waste reuse from the tile-making process.
- Reducing energy consumption, CO_2 emissions, and related environ-mental impacts.

In regard to **reducing natural raw materials**, several ongoing research projects are looking at opportunities for producing ceramic products with high percentages of recycled raw material (Zanelli et al., 2021; Castellano et al., 2021; Rambaldi, 2021), with up to 85% replacement of raw materials with sodium-calcium glass waste and unfired ceramic waste. That undoubtedly would entail significant reductions in natural raw materials, energy consumption and CO_2 emissions.

At this point, it is worth mentioning several research projects championed by both the Instituto de Tecnología Cerámica (ITC) in Castellon and Centro Ceramico di Bologna (CCB):

- **REWACER:** is a project funded by the Autonomous Government of Valencia (GVA) and the European Union, and co-ordinated by the water supply firm FACSA. It aims to develop a circular economy model that ensures circularity of treated water from Wastewater Treatment Plants for industrial use.
  https://www.itc.uji.es/idi/economia-circular/rewacer/

- **iWays,** funded under the European Union's H2020 programme, focuses on increasing water efficiency through three main solutions: exhaust gas condensation, water treatment, and waste reuse.
  https://www.iways.eu/

- **LIFE EGGSHELLENCE** is a project funded through the EU's LIFE programme which seeks to reuse the approximately 150,000 tons of eggshell that are produced in Europe to obtain calcium carbonate. www.lifeeggshellence.eu

- **WINCER,** an EU-funded project that aims to develop innovative ceramic tiles containing more than 70% by weight of recycled materials from urban and industrial waste. http://www.wincer-project.eu

- **LIFE Foundrytile** is a project funded by the European Commission's LIFE programme that studies the use of by-products from foundry industries to incorporate them as raw materials for the production of ceramic tiles. https://www.foundrytile.eu

- **Iceberg** is a project funded by the European Commission's Horizon 2020 programme that searches for innovative solutions based on the circular economy as a means of demonstrating the efficient recovery of valuable material resources sourced from representative building materials at the end of their service life. Among other projects, the manufacture of ceramic tiles with high-purity recycled construction materials is being studied. https://iceberg-project.eu

As far as **reducing energy consumption,** CO_2 emissions, and associated environmental impacts is concerned, the existence of a number of studies aimed at adapting the sector to the decarbonisation requirements foreseen for 2030 and 2050 is worth mentioning:

- **HIPOCARBÒNIC** is a project funded by the Valencian Institute for Business Competitiveness (IVACE), in which a specific roadmap is being developed to decarbonise the Castellon ceramic sector. https://www.itc.uji.es/idi/energia/hipocarbonic/

- **ENERGÈTIC** is a project funded by the Valencian Institute for Business Competitiveness (IVACE), in which various alternatives for reducing energy consumption or replacing natural gas with other types of energy are being studied. https://www.itc.uji.es/idi/energia/energetic/

- **CEr-Oh! Strategies** is a project funded by the Valencian Institute for Business Competitiveness (IVACE) that studies opportunities for reducing CO_2 emissions in firing by changing ceramic body compositions. https://www.itc.uji.es/idi/energia/cerohstrategies/

One can see, therefore, that various strategies and lines of work are underway, whose objective is to transform the ceramic industry according to circular economy models to generate more sustainable products.

STAGE 2: DESIGN, INSTALLATION AND USE OF CERAMIC TILES

As was the case with tile manufacture, energy is consumed and waste generated during the process of installing or fixing ceramic tiles, so those are the fundamental aspects that need to be improved at this stage. The guidelines to be followed to achieve ceramic coverings that meet the principles of the circular economy are the following:

- Extending the service life of the building and its components to the maximum.
- Using recycled and/or recyclable materials.
- Minimising and efficiently managing waste so that it can be reused.
- To minimise energy consumption.
- Reducing water consumption.
- Promoting the well-being of people.

In regard to the **service life of buildings**, current building regulations define a useful life of at least 50 years, which is often well overrun. However, as Ortega (2012) defined, different criteria need to be considered, such as appearance, functionality, or safety, depending on the specific element, materials, and construction solution in each case.

In this sense, properly installed ceramic floor and wall tiles are highly durable from the point of view of their functionality, safety, and preservation of initial appearance. However, they can have certain aesthetic problems, mainly due to changes in fashion and vogue that exclude certain tiles from the market. The strategies to be applied to enhance ceramic tile strong points are an adequate choice of products, proper installation to prevent premature deterioration, and the specification of products with timeless aesthetics.

The use of **recycled** and/or **recyclable materials** is inherent in the nature of ceramic tiles. As already mentioned above, tile manufacture can include the incorporation of large amounts of ceramic waste and, furthermore, as that waste is inert, it can be used in other manufacturing processes, either of ceramic products, as aggregates (Pitarch et al., 2019) or as a partial substitute for cement (Pitarch et al., 2020). The best strategies to encourage the reuse or recycling of such materials are those that facilitate their selective dismantling, mainly by using dry installation systems.

The **minimisation and efficient management of waste** depends on several issues, such as selecting formats that fit the actual space available, for which it is necessary to choose the right format and also to ensure products exist that are manufactured to measure or pre-cut at the factory. In either case, waste generated on site needs to be suitably managed to facilitate subsequent treatment.

Some ceramic products already have special features that enable **mitigation of the building's energy consumption** throughout their service life, or which even have decontaminating, bactericidal or viricidal properties, which undoubtedly contribute to **people's well-being and health.**

Similarly, some outdoor paving solutions enhance **rainwater drainage,** thus preventing wasted runoff and enabling that water to be reused in the garden.

Another very interesting principle when it comes to optimising construction processes is that of **prefabricating buildings or construction parts** since it leads to better use of materials and energy and less waste generation.

In this regard, several research projects have improved the performance of ceramic systems to make them increasingly sustainable:

- **CERBUILD** is a project funded by the Valencian Institute for Business Competitiveness (IVACE) and co-ordinated by ITC that aims to design and promote industrialised ceramic construction systems that provide companies in the ceramic sector with access to industrialised construction. https://www.itc.uji.es/idi/edificios/cerbuild/

- **PRESTILE** is a project funded by the Valencian Institute for Business Competitiveness (IVACE) and co-ordinated by ITC that aims to improve the performance of ceramic tiles in the rehabilitation of indoor flooring. https://www.itc.uji.es/idi/edificios/prestile/

- **LIFECERSUDS** is a project funded by the EU's LIFE programme in which a sustainable urban drainage system (SUDS) has been developed that uses low commercial value ceramic material as a flooring filter system. http://www.lifecersuds.eu

- **HIDROCER** is a project funded by the Valencian Institute for Business Competitiveness (IVACE) and co-ordinated by ITC that aims to develop ceramic solutions for façades capable of reducing the electricity required for air-conditioning by over 90% in buildings in Mediterranean climates using evaporative cooling.
  https://www.itc.uji.es/idi/edificios/hidrocer/

Although a number of research projects have significantly improved the sustainability of ceramic tiles, from the point of view of circularity, there still remain many opportunities for improvement, principally based on pre-fabrication and the development of dry installation systems, which enable the use of materials to be optimised and in turn facilitate selective dismantling at the end of the building or the ceramic tile's useful life.

STAGE 3: END OF USE

Once the usage stage of a building or construction part has finished, it is demolished, which, according to circularity criteria, must be carried out in a way that enables maximum reuse of existing materials. To facilitate such "urban mining", it is recommended that the following aspects be considered from the initial building design stage:

- Ease of selective dismantling/demolition.
- Use of non-polluting materials.

To achieve that, as stated above, it is necessary to research more profoundly into systems that enable **selective disassembly**, either by using dry installation systems or binder systems with inert materials that can subsequently be processed along with the ceramic waste.

Moreover, in order to favour the management of the waste produced when a building is demolished, the use of materials that are difficult to recycle or that pollute, generating waste after the service life of the building has concluded, should be avoided.

5. CONCLUSIONS

As indicated in the sections above, ceramic coverings have many opportunities to adapt to the principles of the circular economy. For example, recycled materials are already being used in tile manufacture, generated waste is being recycled into the process, and more sustainable energy sources are being researched.

As far as tile fixing systems are concerned, a number of experiments using prefabricated and dry installation systems have taken place, and those new techniques are currently being consolidated. In any event, owing to their own characteristics, ceramic tiles and adhesives are inherently inert materials that can easily be crushed and incorporated into the manufacture of other construction products.

In light of all this, tile manufacturers, specifiers and tile fixers alike face an interesting challenge: to adapt these products that perform so well in many respects to the principles of the Circular Economy.

6. REFERENCES

[1] ASCER *Cuadro de indicadores. Sector español de baldosas cerámicas*. Spanish Ceramic Tile Manufacturers' Association. 2020. https://www.ascer.es/verDocumento.ashx?documentoId=919&tipo=pdf Retrieved September 2021

[2] ASCER. News item: *El azulejo español busca diferenciarse por su sostenibilidad*. Spanish Ceramic Tile Manufacturers' Association. 2021 https://www.ascer.es/prensaNoticias.aspx?cual=sector&returnURL=default.aspx?lang=es-ES&lang=es-ES&id=11960 Retrieved September 2021

[3] L. Baraldi – *World production and consumption of ceramic tiles* MECS / Centro Studi Acimac. 2020 https://www.ceramicworldweb.it/cww-en/statistics-and-markets/world-production-and-consumption-of-ceramic-tiles-the-figures-for-2019-and-forecasts-for-2020/ Retrieved September 2021

[4] J. Castellano, E. Cañas, V. Sanz, E. Sánchez, *Valorización de residuos de diferentes industrias en la fabricación de baldosas cerámicas*. IX Simposio Iberoamericano en Ingeniería de Residuos. Panama 2021.

[5] CEDEX, 2014. Center for Studies and Experimentation of Public Works- Ministry of Development. Spanish Government: *Catálogo de residuos. Ficha residuos de construcción y demolición*: 1–50 [online]. http://www.cedex.es/NR/rdonlyres/0AF8BEF6-2BE2-4456-AE0C-7181B3A2975B/119974/RESIDUOSDECONSTRUCCIONYDEMOLICION1.pdf. Retrieved March 2017.

[6] European Commission, *Energy efficient buildings* https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings Retrieved September 2021

[7] European Commission *Regulation (EU) 2019/2021 of 1 October 2019 laying down ecodesign requirements for electronic displays pursuant to Directive 2009/125/EC of the European Parliament and of the Council, amending Commission Regulation (EC) No 1275/2008 and repealing Commission Regulation (EC) No 642/2009* https://eur-lex.europa.eu/legal-content/ES/TXT/?uri=CELEX:32019R2021

[8] European Commission (European Green Deal) https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal_es Retrieved September 2021

[9] European Commission (A new Circular Economy Action Plan) *Communication From The Commission To The European Parliament, The Council, The European Economic And Social Committee And The Committee Of The Regions*. European Commission, Brussels, 2020 https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN

[10] CONAMA, *Economía Circular en el sector de la construcción. RUMBO 20.30*. Grupo de trabajo GT-6 Congreso Nacional del Medio Ambiente 2018 Fundación Conama http://www.conama.org/conama/download/files/conama2018/GTs%202018/6_final.pdf Retrieved September 2021

[11] D.W. Pearce, R.K. Turner, *Economics of natural resources and the environment*. American Journal of Agricultural Economics 73(1). February 1991 DOI:10.2307/1242904

[12] L. Ortega Madrigal, Ph.D. dissertation *Propuesta metodológica para estimar la vida útil de los sistemas constructivos de fachadas y cubiertas utilizados actualmente con más frecuencia en la edificación española a partir del método propuesto por la norma ISO-15686.* Universitat Politécnica de Valencia December 2012. https://riunet.upv.es/bitstream/handle/10251/27666/Tesis_Durabilidad_LeticiaOrtegaMadrigal.pdf%5B1%5D.pdf

[13] A. M. Pitarch, L. Reig, A.E. Tomás, F.J. López. Effect of Tiles, *Bricks and Ceramic Sanitary-Ware Recycled Aggregates on Structural Concrete Properties*. Waste and Biomass Valorization, 2019, 10 (6), 1779–1793. DOI: 10.1007/s12649-017-0154-0

[14] A. M. Pitarch, L. Reig, A.E. Tomas, G. Forcada, L. Soriano, M.V. Borrachero, J. Payá, J.M. Monzó. *Pozzolanic activity of tiles, bricks and ceramic sanitary-ware in ecofriendly Portland blended cements*. Journal of Cleaner Production, 2021, 279, 123713. DOI: 10.1016/j.jclepro.2020.123713

[15] E. Rambaldi. *Pathway towards a high recycled content in traditional ceramics*. *Ceramics* **2021**, *4*(3), 486-501; https://doi.org/10.3390/ceramics4030036

[16] RCDA, 2015. *Informe de Producción y Gestión de Residuos de Construcción y Demolición (RCD) en España*, Asociación Española de Reciclaje de Residuos de Construcción y Demolición. http://www.rcdasociacion.es/images/documents/Informe-RCDA-11-15.pdf. Retrieved October 2017.

[17] WEF, *Shaping the Future of Construction – A Landscape in Transformation: An Introduction World Economic Forum 2016* https://www3.weforum.org/docs/WEF_Shaping_the_Future_of_Construction.pdf Retrieved September 2021.

[18] A. Zanelli, S. Conte, C. Molinari, R. Soldati, M. Dondi, *Review Waste Recycling in ceramic tiles: a technological outlook.* Resources, Conservation & Recycling 2021, 168, 105289. https://doi.org/10.1016/j.resconrec.2020.105289

7. ACKNOWLEDGEMENTS

This study was carried out in the context of the Chair in Circular Architecture and the Ceramic Classroom of Universitat Jaume I.

The Chair in Circular Architecture was created by a collaboration agreement between UJI and the Second Vice-Presidency of the Council and Regional Department of Housing and Bioclimatic Architecture.

The Ceramic Classroom was created by a collaboration agreement between UJI and the Spanish Ceramic Tile Manufacturers' Association (ASCER), with funding by the Regional Department of Inland Revenue and Economic Model of the Autonomous Government of Valencia (GVA).