CERBUILD PROJECT: CERAMIC SYSTEMS FOR INDUSTRIALISED CONSTRUCTION

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ABSTRACT

Industrialised construction (IC) is a construction system in which the structural components of a building are made in the workshop and transported to the final location and assembled on site. Despite its difficult implementation in a sector as traditional as construction, industrialisation brings numerous benefits in terms of sustainability from the **environmental, economic** and **social point of view.**

This model of construction makes it possible to reduce wastage and execution times on site, with greater control over costs and fewer occupational accidents, as well as providing more stable employment and an improved balance between work and family life for workers, etc. The industrialization of construction heralds a true alternative with which to tackle the problems currently facing the building industry and to respond to major global trends in terms of sustainability and digitalization.

Such is the context in which the **CERBUILD project** is born, with the direct aid of the **Valencian Institute for Business Competitiveness (IVACE),** which pertains to the Valencian **Regional Authority for Economic Affairs (GVA)**. The aim of the project is to design and promote **industrialised ceramic systems** that offer companies in the ceramic industry a window into this new form of construction.

The project was devised as a vehicle with which to explore the industrialization sector and define its characterization, in order to propose construction systems and development strategies in which ceramics can play a key role and thus, open the door to the industry for the ceramic tile sector.

To carry out that characterization, the **actors** involved in industrialised construction processes had to be assessed: specifiers, prefabrication firms, construction companies, property developers, associations, etc. At the same time, a study was run of the **construction solutions** currently available on the market, with the focus on the most widely used materials and backed by a newly designed and implemented permanent **technology watch system.** In the end, different **systems** are proposed and a number of **strategies** identified in which ceramic materials can play a leading role.

1. INTRODUCTION

The construction industry has always been a sector based on traditional systems. By way of an example, it suffices to see how two materials as common in building as ceramic brick and tiles have evolved over the last few hundred years. Although today sees the implementation of modern technology to manufacture those products, their supply and installation on site remain, in most cases, the same as have been used for centuries (Esteban, 2020).

However, the context in which we find ourselves today calls for a change of direction, given that, according to figures published by the European Commission, the construction industry in Europe accounts for 40% of total energy consumption, produces 36% of CO_2 emissions, is responsible for a third of all water consumption, and a third of all waste generated. In this sense, industrialised construction (CI) is believed to offer the means with which the sector can adapt to Europe's increasingly demanding sustainability and energy efficiency regulations and provides a vehicle of transformation that will enable it to move towards decarbonisation.

Although IC is not a new concept, major global trends concerning sustainability and digitalization, to which society is highly sensitive, make industrialization the necessary lever of change for many stakeholders in the sector, who see these new construction systems as a real alternative that will completely transform traditional building.

SUSTAINABILITY AND DIGITALISATION

IC can be defined as a set of methods that make it possible to develop construction processes that employ intelligent manufacturing and automation techniques in building. It is therefore an umbrella term that includes the design, production, transport and assembly of building components and structures, and which encompasses the different types of pre-fabrication and **off-site construction**.

The manufacture of industrialised construction parts takes place in a highly controlled "technologized" environment, from where they are subsequently transported to the final location and assembled on site. In-factory manufacturing means that some of the most important issues facing the construction industry today can be overcome, such as occupational accidents and the lack of specialist labour. In-factory production reduces common hazards on a conventional construction site, as different health & safety measures can be implemented. In addition, it also makes it easier to improve workers' quality of life by offering a better balance of work and family time, more stable employment and, finally, women's participation in the production chain. These improved working conditions help to attract labour and increase worker specialisation (Alcarazo, 2020).

From the environmental point of view, off-site construction can contribute to sustainable development, since it is estimated that factory-based processes significantly reduce the generation of waste, the use of raw materials, and the consumption of energy during the building's construction stage. In addition, industrialisation encourages the design of more efficient systems, both technically and energetically, which also contribute to lower energy consumption during the building's service life. Finally, if the circular economy component inherent in the design of many of such systems is included, IC also contributes to reducing the various impacts produced when the building is demolished (Alcarazo, 2020).

However, it is important to take the distance between the production site and construction site into account, as, depending on the proximity or distance between the two and the weight/volume ratio of the industrialised construction parts, the emissions caused during transport may be too high.

Another significant advantage of IC is shorter construction times and greater control over costs, thanks to increased productivity, shorter delays, and fewer unforeseen events occurring on site.

Finally, in the context of a "fourth industrial revolution", the construction industry must eventually tackle the challenge of its digitalization with the continuous improvement of industrialised construction processes with the incorporation of new manufacturing technologies (machinery and robotics) and innovative methods (Lean Manufacturing, BIM, etc.), to optimise the use of resources and maximise process efficiency. In view of all this, the construction industry could increase productivity by adapting its production systems to embrace a technological transition in which automation and data or information will play a key role in such a transformation process (Saieg, 2018).

2. ACTORS IN INDUSTRIALISED CONSTRUCTION

Identifying the actors in the IC sector and understanding their role in such new building processes is key to understanding how it operates. At present, the IC sector encompasses a great diversity of companies. An overview of the network and the relationships between the different actors involved is given below:

MANUFACTURERS

At national level in Spain, two types of companies can be distinguished in the IC sector:

- **Manufacturers of industrialised modular systems**. These are companies that manufacture wall panels or large items from various materials, such as concrete, steel or wood (1)[a]. Most of these companies offer a fully comprehensive service that runs from the manufacturing stage to final assembly of the system on site.

- **Manufacturers of industrialised housing.** This is an emerging market in which companies offer turnkey modular homes (2) and that are sometimes associated with architecture firms (3).

In Europe, the market for industrialised housing is fairly consolidated in central and northern Europe through firms with an international reputation (4) that offer industrialised systems, usually based on wooden structures.

At international level, certain countries are more prominent, such as Canada, the USA, Australia and Japan, where a number of manufacturers (5) cover the entire process of design, manufacture and assembly of homes and public buildings. In these cases, different materials are combined with predominantly wooden frame structures, and some even have a wooden outdoor finish.

PROPERTY DEVELOPERS/BUILDERS

Large construction and development firms are adapting to this new environment by adjusting their business structure through the creation of divisions in their network dedicated exclusively to industrialization, or by directly creating new companies focused on this specialist market.

In Spain, on the one hand, **property developers** offer products built with prefabricated or dry-assembled systems (6), which enable them to optimise processes, costs and sale prices, and include a higher quality end product as added value. On the other hand, **building contractors** have chosen to implement industrialised systems in their construction processes (7).

[a] The numbers in brackets refer to example companies listed in Table 1, Section "7. REFERENCE FIRMS".

SYNERGIES BETWEEN DIFFERENT ACTORS

As Alimarket's report on IC pointed out (Temperate, 2020), 2019 was a turning point in the Spanish IC sector in terms of commercial collaboration agreements between different actors. Some of those agreements included in the aforementioned report are highlighted below:

A well-known construction company specialising in industrialization (7) entered into various collaboration agreements in 2019. On the one hand, the report cites the agreement reached with the subsidiary of an important ceramic manufacturer specialising in construction systems (8) to integrate its industrialised bathrooms and kitchens in projects carried out by one of the construction firm's divisions. Another example is the agreement reached with the IC subsidiary of one of Spain's leading pre-cast concrete groups (9) to use its industrialised façade system in a number of the building projects they are constructing.

A further initiative saw one of the Spain's largest property developers (6) closing different agreements to incorporate into its projects, firstly, the industrialised bathrooms and kitchens made by a well-known Almeria-based company specialising in the sector (10), and secondly, with a leading Valencian company to use its industrialised façade panels (11).

3. INDUSTRIALISED CONSTRUCTION SYSTEMS

Today, numerous companies in the construction business are already offering industrialised products and systems. They can all be classified by the degree of industrialisation to which they have been subjected in their construction and commissioning. The offer ranges from materials or systems with a scant degree of industrialisation, designed to be incorporated into more or less conventional building processes, to systems with a high degree of industrialisation that reduce on-site construction to a mere assembling of components.

INDUSTRIALISED CONCRETE SYSTEMS

One of the most common industrialised systems in Spain is concrete panelling. In general, these systems are formed by load-bearing panels, both as outer enclosure walls and indoor partition walls, which are made with all the functional layers needed to deliver the performance level required of each construction.

There exist other systems (12) that are more focused on residential usage and include more careful finishes, both indoors and out. They usually comprise an outer layer with a prefabricated concrete finish, a middle layer that provides the heat and sound insulation, a load-bearing inner layer of prefabricated concrete (which can house all necessary utility services) and, finally, the interior top layer.

This same heading includes systems and/or products that are directed more specifically at industrial usage (13). These systems are produced by companies with a degree of tradition and experience in the Spanish market, dedicated to manufacturing all kinds of prefabricated concrete items, from pillars, beams and slabs to complete façade systems (14).

INDUSTRIALISED WOOD SYSTEMS

Across the country, different firms can be found that specialise in manufacturing industrialised wood-based systems. They tend to be companies with their own manufacturing capabilities that offer systems for projects aiming to achieve high standards of energy efficiency.

Some of them (15) have their own systems capable of adapting to the needs and demands made by different construction sectors and who are able, with very small changes, to produce panels suitable for interior partitions, outer façades, flooring and roofing. These are timber-frame systems, made up of large-format boards that rest on wooden beams or brackets. The panels act as load-bearing elements and are fixed to the other structural components by dry fixing systems. The gaps between beams are filled with insulating material.

A further series of companies (16) specialise in making reinforced timber structures, laminated timber structures, or cross-laminated timber (CLT) structures, and also offer the full range of industrialised manufacturing of complete panel solutions.

INDUSTRIALISED STEEL SYSTEMS

Here, a few firms dedicated to producing façade panels have developed industrialised systems for the construction of building envelopes. Some of these systems comprise a kind of steel perimeter frame, stuffed with heat insulation, and with built-in anchoring and levelling systems. These panels come with the metal window frames and glass fitted in the factory, as well as with the outer panel finish, which can range from a ventilated façade to single-layer tiling.

INDUSTRIALISED VOLUMETRIC SYSTEMS

Another member of the IC community are systems based on volumetric items. Unlike the systems described in the previous sections, the solutions that form part of this group are characterised as large three-dimensional modules. These modules are generally produced on an assembly line and are fully fitted with their accessories when they leave the plant.

Such systems include reinforced concrete modules (2), hybrid concrete-steel modules (17), and steel-frame modules (18). Unlike the systems described above, the main drawback with these parts lies in transporting them from the factory to the building site.

INDUSTRIALISED CERAMIC SYSTEMS

Today's market also offers industrialised ceramic systems, which can be classified by the field they are applied to:

- Solutions for indoor spaces. Prominent among these are dry fitting systems for use as flooring or wall cladding (19). Despite the benefits they afford from the technical and installation point of view, these systems have still not consolidated their place on the market.
- Volumetric kitchen or bathroom units (10). The ceramic material is fitted as the inner wall cladding and they are delivered with utility services ready for assembly on site.
- Building envelope systems. In recent years, new technical solutions have been developed such as ceramic ventilated façade systems, dry fitting of small ceramic tiles on a metal frame (20), ceramic fabrics (21), ceramic panels for outdoor heat insulation systems (22), or multi-layer panel systems with a ceramic finish (8).

TECHNOLOGY WATCH SYSTEM

In order to keep up-to-date information on such systems, a Technology Watch scheme was devised, based on state-of-the-art data mining, analysis and display software **Figure 1** This vanguard technology enables all manner of tasks to be carried out more effectively, since it can combine data from different sources, which is then analysed much more thoroughly. Furthermore, the dashboard updates continuously, unlike traditional reports or graphic displays, and automatically enters any new contents and values that match its pre-set parameters.

As a result, it generates a dynamic, permanently updated information system, as opposed to a traditional written report, where it is more difficult to analyse data and that data may even be expired or outdated because of its static nature. Another great advantage is its interactivity, which offers a global display of the information while also allowing for detailed study or analysis of the different variables, indicators and KPIs that are featured in the tool by setting filters and display dimension parameters.

The information provided by the tool for this project is drawn from patents, scientific articles, the Internet, and social media. The data can be organised by other customised criteria and keywords that form the core of its searching and enable quick access to different sets of information. Depending on the specific topic of interest, the tool can be adjusted by changing the group of keywords and thus the results fine-tuned with great accuracy. Moreover, in regard to social media, the origin of the various messages or contents are displayed on a map, thus indicating the regions where more chats or messaging about a particular target topic are generated.

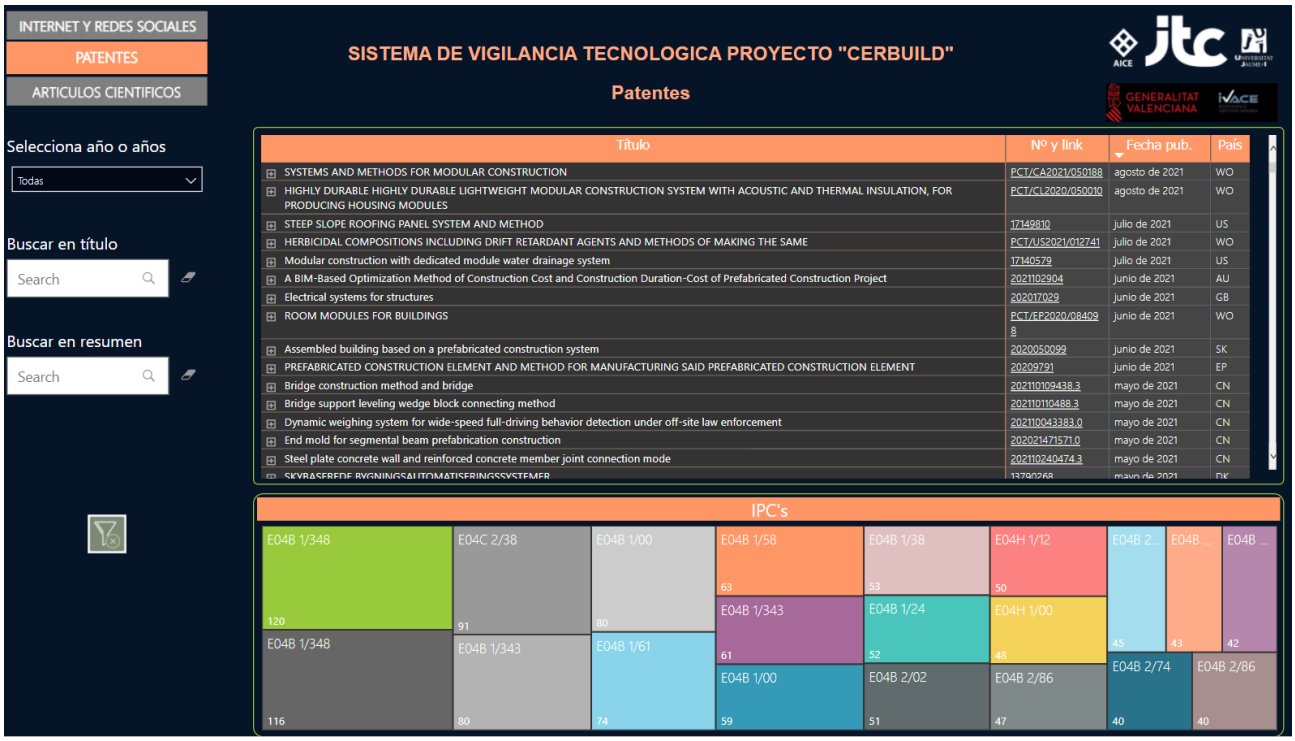

Figure 1. *Technology watch system interface (patents)*

4. IDENTIFYING STRATEGIC LINES FOR THE CERAMIC SECTOR

Having assessed the current situation of IC in Spain and taking into account the various actors that play a part in its construction value chain and the most commonly available systems, it is time to look at how such new industrialised construction systems represent a great opportunity for improving the characteristics of ceramic systems and responding to society's current demands.

As mentioned above, although the production of ceramic material has reached a significant degree of industrialisation by incorporating digital manufacturing techniques and processes, actual fitting or installation of ceramic tiles remains a mostly traditional process.

On another note, the trend in the ceramic industry towards **increasingly large and slimmer formats** calls for some reflection about their use on site in order to improve the installation process. Therefore, the **industrialisation of ceramic systems** is seen as a path that could lead to construction solutions built in fully controlled environments with improved characteristics and which perform better than conventional systems.

In today's context of ecological transition and decarbonisation, **energy efficiency** is one of the main resources available to the construction sector to meet such challenges (Green Building Council, 2020). Therefore, designing industrialised construction solutions that improve the energy efficiency of a **building's skin**, whether new or rehabilitated, is another of the goals that our sector should set itself.

With all the above in mind, **three strategic lines of business** for the ceramic sector within IC have been identified:

CERAMIC DRY INSTALLATION SYSTEMS

The first line of business refers to alternative systems to traditional ceramic tile installation, both for flooring and wall cladding. These systems are designed to circular economy criteria and for low environmental impact, which make assembling (and also replacing and dismantling) the product on site easier, thus minimising the amount of waste generated during installation and at the end of its service life.

MULTI-LAYER CERAMIC SYSTEMS

These are panels with a ceramic finish, made up of different layers, which are delivered ready to fit on site. There are two large groups within this line of business:

- Systems for indoor construction solutions: composed of multilayer panels suitable for fitting as **partition walls and ceilings** and which provide the construction system that they form part of with specific characteristics or features.
- Systems to improve energy efficiency: composed of multilayer panels for use in the building **envelope** (façades and roofs), designed for both newbuilds and the rehabilitation of the existing building stock.

VOLUMETRIC SYSTEMS

This last line of business encompasses **three-dimensional** systems ranging from whole houses to individual rooms, such as bathrooms and kitchens, where ceramic cladding is used. These systems comprise numerous components, fully assembled at the factory before being transported and delivered on site ready to fit and connect to the various utility circuits. The only restriction on the dimensions of these bulk elements, which are usually formed by lightweight galvanised steel structures, is the maximum size that will fit on the means of transport used to haul it from the production plant to the site.

5. DEFINITION OF SYSTEMS TO BE DEVELOPED

After analysing the industrialised systems that exist on the market and identifying lines of business that are strategic for the ceramic sector, this project moves on to propose other systems that can be designed and developed. To develop the systems, various proposals were put forward and sorted by the type of application and degree of industrialisation they require.

In regard to the APPLICATIONS that such industrialised systems would respond to, industrialised construction solutions have been identified for indoor partitions walls and ceilings, building enclosures (roofs and façades), and for urban spaces (flooring). In the end, another category was added where special systems that do not easily fit into the more traditional construction solutions can be grouped (others).

With respect to the systems' DEGREE OF INDUSTRIALISATION, the following was defined:

- **Level 1. COMPONENTS.** Made up of more basic solutions that entail combining ceramic tiles with any other construction material. Also included in this category are dry installation systems, formed by a material with its anchoring scheme.
- **Level 2. PANELS.** This comprises more complex construction solutions involving the assembly or combination of various components and materials, together with their anchoring schemes, ready to be installed on site.
- **Level 2+. SMART PANELS.** These are systems comprising different components as in Level 2, but which also have built-in devices such as sensors and actuators.
- **Level 3. UNITS.** These are industrialised systems formed by a collection of panels to create three-dimensional modules.

The chart below shows the various proposals for developing industrialised systems, classified by these two parameters:

<table>
<tr><th rowspan="3">APPLICATIONS</th><th colspan="4">DEVELOPMENT OF OFF-SITE CERAMIC PRODUCTS/SYSTEMS</th></tr>
<tr><th colspan="4">LEVEL OF DEVELOPMENT</th></tr>
<tr><th>LEVEL 1 COMPONENTS (COMBINATION OF MATERIALS)</th><th>LEVEL 2 PANELS (COMBINATION OF COMPONENTS)</th><th>LEVEL 2+ SMART PANELS (COMBINATION OF COMPONENTS + SENSORS + ACTUATORS)</th><th>LEVEL 3 LARGE-VOLUME ITEMS (COMBINATION OF PANELS)</th></tr>
<tr><td>Vertical partitions</td><td></td><td>Ceramic panels with dry fastenings</td><td></td><td></td></tr>
<tr><td>Horizontal partitions</td><td>Ceramic concrete with ceramic scrap</td><td colspan="2">Multi-layer panels</td><td></td></tr>
<tr><td>Roofs</td><td>Roofing slabs</td><td></td><td>Collector panels</td><td></td></tr>
<tr><td rowspan="2">Façade walls</td><td rowspan="2"></td><td>Large format façade panels small format tiles</td><td>Active Ventilated Façade module</td><td></td></tr>
<tr><td>Lightweight ETICS panels</td><td>Solar protection modules</td><td></td></tr>
<tr><td>Others</td><td></td><td></td><td></td><td>Pergolas</td></tr>
</table>

***Figure 2**- Classification of ideas for system development*

The following are some of the ideas that have been selected as systems to be developed under the project:

- **Prefabricated concrete with recycled ceramic tile waste as aggregate.** This is a system developed in collaboration with the TECASOS research group based on producing concrete in which natural aggregates were replaced by ceramic tile waste (Debueno, 2016). Within this line, the proposal envisages designing and developing prefabricated panels with different features, to be used as flooring in public spaces or for roofing.

- **Lightweight ETICS panels**. A lightweight external thermal insulation composite system consisting of ceramic slabs, insulating material and the anchoring scheme. In this case, the compatibility of different ceramic materials with the most common insulation materials used in this type of system has been assessed. Specifically, how it behaves in respect to different stresses, such as impact with a hard or soft body or resistance to freeze-thaw cycles, has been studied. Based on the results, a ceramic ETICS system is currently being developed.

- **Active ventilated façade modules.** The active ventilated façade module proposed here incorporates sensors and actuators that allow the hot air from the cavity to be reused. Depending on the temperature inside, outside and in the cavity, the actuator opens louvers to allow the hot air to enter the air circulation system, or to exhaust it outside the building.

6. CONCLUSIONS

IC stands for a clear commitment to sustainability, efficiency and continuous improvement of construction processes. It is a profound transformation of the construction sector from which the ceramic industry can benefit. To that purpose, it is necessary to establish **alliances** between the various stakeholders involved (architects, property developers, construction companies, manufacturers of construction materials, and companies supplying industrialised systems), to encourage the design and development of ceramic construction systems that adapt to the needs of IC.

The industrialisation of construction systems and processes is seen as the necessary tool with which the building industry can face the changes it will be subjected to in the coming years. Therefore, it is important that the ceramic industry promotes the **design and development of ceramic construction systems** that fulfil those new needs - systems that account not only for improvement and optimisation at the material production or system manufacturing stage, but also during its installation, service life, replacement, end of life, and valorisation.

This presentation has characterised the industrialised construction sector by identifying the most relevant actors involved in the process, assessing different industrialised construction systems for both ceramic and other materials, and developing a technology watch system. Following that characterisation of the IC sector, various strategic lines of interest for the ceramic sector have been identified and the development of a number of industrialised ceramic systems has begun.

7. COMPANY REFERENCES

Summary of referenced companies (1)	
(1) Thermochip / Exsitu (Cándido Zamora Díaz) / Barcelona housing systems (BHS) / Compact Habit (Constructor a d'Aro)	(12) Projects' modulars prefabricats (Prêt-à-Porter Casas) / Hormipresa Living / Homitech
(2) Modular system global (Modular Homes) / Arquima	(13) Indagsa (Grupo Ortiz) / Hormipresa industrial
(3) Ubiko y Viraje / iHouse y bAd Arquitectos / Niuhouses y Fran Silvestre	(14) Prefabricados Pujol
(4) Polcom Group / Vision modular systems / Lindbäcks	(15) WES (Wood Engineering Systems)
(5) Factory OS / Katerra / Daiwa House / Sekisui House	(16) Egoin
(6) Offsite (Aedas Home) / Vía Célere	(17) inHAUS / Atlantida Homes
(7) Grupo Avintia	(18) Cintac
(8) Unitsystem (Butech / Grupo Porcelanosa)	(19) kerfloat (Azulev grupo)
(9) ExSitu (Grupo Cándido Zamora)	(20) Corium Brick Tile Cladding (Wienerberger)
(10) Cubik (Hydrodiseño Global)	(21) Flexbrick
(11) Spans Europa	(22) Termoklinker (La paloma Cerámicas)

Table 1. *References to companies in the Industrialised Construction sector*

8. REFERENCES

[1] Alcarazo, E. (2020). Industrialización. *Libro blanco sobre la industrialización de la construcción*, 36-41. Retrieved from https://www.economiadehoy.es/adjuntos/65852/201202_LIBRO-BLANCO_INDUSTRIALIZACION_GRUPO-AVINTIA.pdf

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