Industrial Symbiosis for the Circular Economy: Operational experiences, best practices and obstacles to a collaborative business approach.

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1 ALL YOU CAN'T EAT: research and experiences from agri-food waste to new building products in a circular economy perspective

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Abstract

In a Circular Economy perspective, agri-food can play an important role, since the majority of waste consists of by-products potentially used as secondary raw materials in several industrial processes, including the building sector.

The chapter deals with some outcomes achieved in research projects carried out by TeAM of Politecnico di Torino in partnership with some SMEs. In particular, it describes a cluster of research projects and experiences entitled ALL YOU CAN'T EAT, focusing on the recycling of agricultural by-products and food waste: both are used for developing new products for the construction industry and for promoting the transition from "waste" to "resource". Despite the results achieved, the paper highlights some open issues that must be considered when moving from experimentation to industrial production, such as: is the amount of waste sufficient to be put into a new production cycle and to ensure the continuity of the supply chain (and its economic sustainability)? Does a circular product really have a lower environmental impact?

The chapter highlights the limitations and prospects of developing eco-compatible products with an approach related to industrial symbiosis.

Keywords: agri-food waste, new building products, prototyping and testing, life cycle approach, technical and industrial feasibility, circular economy

1.1 Introduction

The Circular Economy, supported by European Commission policies - since the Action Plan of 2015 (European Commission 2015) - can be a driver of innovation and an opportunity for the construction industry; the use of principles of waste recycling and reuse can lead to a reduction in the environmental impact of building over its lifecycle.

The data recently reported within the document “Towards a circular economy model for Italy” of the Environment Ministry, in addition, give strategic importance to the construction industry in the development of a circular economy, in which the efficient and sustainable use of resources and the utilisation of waste become the keys for a development model that is not merely economic but also environmental and social (Ministero dell’Ambiente 2017).

In this direction, Italy has seen the introduction of CAMs (Minimum Environmental Criteria), public policy tools able to encourage the diffusion of environmentally-friendly materials and to promote products with high recycled content (Decreto Ministero dell’Ambiente 11 October 2017), although there is still no harmonised system of rules and actions.

According to circular economy goals, cooperation projects between enterprises and research organisations have been increasing, along with start-ups specialising in the reuse and recycling of waste and secondary raw materials.

In this context, agri-food waste can be assumed as strategic, since the majority of this waste consists of by-products that can potentially be used as raw secondary materials in several industrial processes.

Based on these premises, the article illustrates some experiences conducted by the TeAM (Tecnologia e AMbiente) Research Group of the Department of Architecture and Design – Politecnico di Torino, aimed at developing eco-building products featuring reused and recycled waste from agro-industrial processes, characterised by the collaboration with some SMEs.

On the whole, the chapter discusses the achievements in the development of a symbiotic process between agronomic and construction sectors, highlighting the constraints and opportunities within a circular economy approach

1.2 From agri-food waste to new building products

1.2.1 Applied research

The TeAM Research Group has been working on developing and prototyping eco-friendly solutions and technologies for construction, featuring reused and recycled waste from agro-industrial and other industrial processes. Most of these cooperation projects, developed in partnership with some SMEs, encourage the transition from the academic experimental approach to product innovation, passing through phases of experimentation and monitoring and – sometimes – filing patent applications. Furthermore, the research is often characterised by Life Cycle Assessment (LCA) studies usually based on a “cradle to gate” approach – in accordance with UNI EN ISO 14040:2006 - in order to predict the avoided environmental impacts. The impacts usually considered are Embodied Energy (Mj or Kwh) and Embodied Carbon (kg). The former quantifies the primary energy demand of a product over its lifecycle. The latter assess the equivalent CO_2 emitted into the atmosphere. The LCA, finally, supports the decision-making process in the circular economy as well as the development of new business models.

In particular, this chapter describes a cluster aimed at developing new materials for the construction industry known as ALL YOU CAN'T EAT, with particular reference to: 1) CONCRICE, develoed with rice husk; 2) THERMALMOND, developed with almond shells; 3) KERATOSTONE, crafted with bovine horns. Moreover, the chapter explores a research, entitled ECOFFI, focused on corncobs and rice straw recycling for the production of concrete blocks.

The decision to use agri-food waste is due: to the quantity of waste generated by the agri-food industry and the respective environmental impact in terms of polluting emissions, global warming, acidification and eutrophication of soil (FAO 2013 data); the specific characteristics of that waste suitable for experimentations in the construction industry (see par. 1.2.2).

The reuse of these residues – currently used for animal fodder and bedding, or incineration - can not only limit the environmental impacts of products, but also reenter the economic system with a new value.

1.2.2 Experiences of international scientific literature relating to agri-food waste

There are various studies in literature oriented towards the development of new building products based upon agri-food waste, such as hemp, straw, olive waste and other vegetable fibres (Madurwar et al. 2013; Liu et al. 2017). They can be used as thermal insulation materials (Liuzzi et al. 2017), bricks (Raut et al. 2011), plaster and concrete (Prusty et al. 2016), etc.

In particular, recent studies conducted by the Centre de Recherche C2MA - Centre des Matériaux des Mines D'Alès have highlighted that untreated rice husk can be used as aggregate and that, thanks to its physical and chemical characteristics, it is able to improve the thermal performances of concrete (Chabannes et al. 2017). Even corn crop residues are used as aggregate in producing concrete, as in the creation of lightened screed having an insulating function for lofts (Pinto et al. 2012) or lightened formwork blocks for vertical perimeter walls and internal partitions

(Faustino et al. 2014). Further interesting applications concern the experimentation of vegetal-based thermal insulating plaster (Carbonaro et al. 2016). Almond shells have been applied in construction for the production of wood-based composites, as a bulk material, exploiting the intrinsic properties of the shell for the purposes of thermal insulation or as a natural aggregate within concrete or limestone mortars for the preparation of plaster (Essabir et al. 2013; Pirayesh and Khazaeian 2012). On the other hand, the use of bovine horns in construction is poorly investigated. Very little literature exists on composites using keratin fibres obtained from animal horns (Kumar and Rajendra Boopathy 2014), although their good mechanical properties are well-known (Bing-Wei et al. 2011).

1.2.3 CONCRICE

“CONCRICE (CONcrete & RIce)” was implemented in agreement with Buzzi Unicem (Casale Monferrato, AL, Italy), a company specialising in the production of cements, concrete and natural aggregates. The research was focused on recycling rice husks as an additive in concrete manufacturing in order to improve its thermal performance.

The availability of the resource is confirmed by the following data: at global level, rice is the world's third most produced grain, with a production amounting to 769 million tonnes (FAO 2017 estimate); Italy is the biggest European producer of rice with its 234,000 cultivated hectares, particularly in the Piedmont and Lombardy regions.

Rice husk owns both physical and chemical characteristics that have encouraged its use in preparing thermal insulating concrete. Its physical characteristics (particular concave and oblong conformation) has enabled the development of a macroporous system inside the cement conglomerate, making it more lightweight and more insulating from a thermal perspective. In addition, the presence of lignin gives greater solidity to the conglomerate.

The experimental activity began by characterising each component of the mixture - aggregates (including rice husk), cement, water and additives - and then continued by preparing concrete containing rice husks. Various specimens were then made with a gradual volume replacement of traditional fine aggregate with rice husk. The requirements of workability, mechanical resistance and thermal resistance were monitored, as required by the technical regulations. CONCRICE can be classified as a lightweight concrete (density on hardened material equal to 1930 kg/m^3 for concrete with 30% rice husk, and 1745 kg/m^3 for that with 60% rice husk), non-structural, with high thermal performances (thermal conductivity λ = 1.02 W/mK for concrete with 30% rice husk, and λ = 0.39 W/mK for that with 60% rice husk).

The market analysis conducted in relation to other similar concretes on the market, thus lightweight and thermal insulating, and concretes with wood based aggregates, highlighted that CONCRICE has similar and even better thermal performances.

Although there is a large potential quantity of by-product, it was also found that the seasonal nature of the rice production and storage methods still to improve do not guarantee the continuous use of rice husk as an aggregate. Contemporaneously an LCA was conducted to verify the incidence of environmental impact in the substitution of rice husks, compared to the aggregates currently used in the building industry. Such incidence was found to be not very significant.

1.2.4 THERMALMOND

the project "THERMALMOND" involved Vimark (Peveragno, CN, Italy), a leading company in the production of natural lime plasters.

During the processing of almond for food purposes, the wood fragments that make up the shell are separated, remaining available as waste product, commonly used by farmers as fuel, fertiliser, biomass generator and cattle fodder.

The aim of THERMALMOND was to reuse this by-product as a natural aggregate within the composition of a thermal insulating plaster, exploiting its physical-mechanical properties and limiting, as far as possible, industrial processes.

Even in this case the availability is potentially remarkable: The production of almonds across the world is approximately 3 million tonnes/year; the United States are the main global producer of almonds, followed by Spain, Syria, Italy, Iran and Morocco. Almond shell amounts for 35-75% of the total weight of the fruit. The production of almonds generates millions of tonnes of residues linked to farming activity, including shells which represent 0.8-1.7 million tonnes of waste/year (Ministero delle politiche agricole, alimentary e forestali 2012/2014; Ebringerova et al. 2008).

The experimental phase involved the formulation of the test mortar prepared in conformity with European standard UNI EN 1015-2:2007, based upon a mix design of a natural premixed dry mineral plaster with high thermo-insulating power, produced at Vimark S.r.l. The study of the new blend was based on three different THERMALMOND mixtures, using almond shells as a natural aggregate with different percentages in weight. The shells, with a particle size of 2-3 cm in length and 1.5-4 cm in diameter, was not undergone to further processing after being separated from the fruit.

The thermal conductivity (λ W/mK) of the material was calculated using the hot plate and the thermal flow meter measurement method, according to the standard UNI EN 12664:2002. The thermal conductivity comparison carried out among the three mixtures THERMALMOND (λ included between 0.121 W/mK and 0.109

W/mK) and the reference product (λ = 0.136 W/mK), shows the shells influence the behaviour of a plaster improving its thermal performance.

By avoiding subjecting the shells to grinding processes, both energy and environmental advantages are gained (fewer processes correspond to saved energy and avoided emissions) along with economic benefits (in terms of production costs of the thermal insulating plaster). In addition, some considerations relating to the supply chain also derive from this: the shells can in fact be transported directly to the plaster manufacturing company or to the site, where they can be aggregated with suitable premixed dry mortars, making this by-product easily available even in areas close to the production locations.

However, without grinding the shells, some processing limits are identified in the product, which cannot be applied by mechanical means but only manually, determining a slowdown in site installation times.

On the whole, it is currently not possible to enhance the performance of a product without compromising - at least partially - the efficiency of the technological-productive system. It is therefore necessary to undertake an industrial improvement, which may be time consuming.

1.2.5 KERATOSTONE

"KERATOSTONE" (from the Greek "Kératos", meaning horn, and the English "Stone") is a project developed in cooperation with a group of small enterprises from Piedmont, Italy, specialising in the collection and reuse of horns and hooves of animals as fertilisers and feed (Globalcibo srl, San Damiano d'Asti, AT; Panamar snc, Scalenghe, TO), and a leading company at global level in the production of Green Building materials (Kerakoll spa), aimed to use bovine horns in the architectural field due to their characteristics of mechanical resistance and durability, very similar to those of stone.

The impact of the activity of rearing and slaughtering cattle is decidedly higher than that of other foods: over 20 kg of CO_2 are emitted (Coop 2013) and 17-43 m^2/year of agricultural land are required for each kilo of consumed meat of adult bovine animals (Nguyen et al. 2010). In addition, consumption of that foodstuff has significantly increased over the last 50 years leading to the availability of numerous by-products or waste deriving from the slaughtering phase.

Horns are made up mainly of a-keratin, a pure structural protein, and do not have mineral or crystalline components. Their compressive strength is 7.6 kN, while a pair of horns can bear a load of 15.2 kN, about three times the weight of an adult bovine (Bing-Wei et al. 2011).

The experimental activity involved a selection phase of the materials and preliminary workability checks. The bovine horns, appropriately treated with bactericides, were boiled to soften the keratin crust, longitudinally sectioned after removing the tips, pressed to be coplanar and finally cut into mosaic tiles. As secondary products, the natural-based pre-mixtures of Kerakoll spa were used.

The experimentation involved a series of laboratory tests. In the absence of a special regulation on the use of bovine horns in the construction field, the standards of the series UNI EN ISO 10545, which regulate the production of ceramic tiles, were used as a reference. All tests performed showed positive results: water absorption coefficient < 10%; tests of resistance to thermal changes and chemical resistance tests passed without clear defects or surface modification; class 5 of stain resistance.

The study of the supply chain was focused within the Piedmont Region, due to the high number of bovine animals slaughtered annually and since it is central with respect to other major breeding and slaughtering areas (Lombardy and France). In particular, a consortium was established on the Coalvi (Consorzio di Tutela della Razza Piemontese) model - a network between breeders, slaughterhouses and the production company of Keratostone - useful for obtaining adequate quantities of the incoming raw material.

Finally, economic aspects were defined relating to: estimate of annual production of mosaic tiles (about 31,250 m^2 per annum of surface area), based upon the available quantities (500,000 animals per year, 1 million horns) and the number of horns necessary by unit of surface area (16 animals per m^2 of surface area); valuation of the cost of raw materials (6 Euro cents per kg for the horn, to which other materials are added) and the processing per m^2; definition of the sale price, also in relation to the analysis of competitors (mosaic systems derived from fruit seeds or shells).

To assess the environmental impacts of the Keratostone mosaic, an LCA study was performed. The analysis revealed that the contributions linked to the manufacturing process of the glass fibre gripping net onto which the mosaic tiles are glued are particularly significant. In the perspective of an improvement of environmental performances, this material could be replaced with one having lesser impact, considering, for example its replacement with a coconut fibre mesh.

Figure 1.1 **Specimens manufactured from agricultural by products and waste. From left to right: Concrice; Thermalmond; Keratostone.**

1.2.6 Boundaries and outlooks

The results achieved in CONCRICE, THERMALMOND and KERATOSTONE investigations have highlighted the opportunities that may derive from the use of waste from agri-food processes as resources for new industrial processes and for the development of new products for construction, revealing, however, some limitations.

In particular, CONCRICE, despite having good thermal performances, did not achieve the expected environmental impacts reduction (based upon an LCA) when compared to the traditional production of concrete.

The end-user company of the THERMALMOND project has been benchmarking, with TeAM Research Group, other fibres deriving from recycling, such as fabric waste and post-consumption cork waste, to assess which best meets market requirements. It is also assessing which is best suited to its production plant, and what possible changes or additions must be made with respect to the existing equipment.

The KERATOSTONE project, finally, requires further assessments in relation to the eco-compatibility of some secondary materials constituting the mosaic, and further supply chain analyses, in relation to identifying a company that is interested to further experimentations, firstly, and then the production of the system.

In general, for all projects, we note as future needs the implementation of aspects with regards to the value proposition, the analysis of the market investigation and the verifications of costs.

The ECOFFI project, described in the paragraphs below, overcomes some of the highlighted limitations. Further it assesses the technical feasibility and environmental and economic sustainability of a new industrial symbiosis model.

1.3 ECOFFI

1.3.1 Concept and methodology

The aim of the "Ecological COncrete Filled FIbers" (ECOFFI) was to develop a new concrete product by developing a new local supply chain, through the recycling of agricultural by-products. The research was implemented as part of an inter-regional cooperation programme among the Politecnico di Torino and Italian and French Small and Medium Enterprises (Sarotto Group srl, Narzole, CN and Vicat Group, L’Isle D’Abeau).

The project involved the following phases:

- Experimental prototyping.
- testing and monitoring of performances.
- Environmental impact analysis through LCA.

• Definition of the industrial supply chain.
• Market analysis.

To assess the availability and feasibility of the reuse of agricultural by-products, an investigation was performed on the supply chains to detect the one which guarantee a greater quantity of crop residues. In Piedmont, corn is the main crop with a cultivated surface area of 140,366 hectares and a potentially available quantity of by-product of 182,475 t. Rice is second with 116,324 hectares of cultivated surface area and a potential yield of 348,972 t of straw.

Currently, the supply chain of corn involves the use of corncob in the production of biogas, as bedding for pets and in the industrial sector for buffing metals; the by-product of rice is little in demand on the market, as in common practice it is considered waste and the supply chains are not incentivised to collect this resource.

1.3.2 Prototyping

A series of experiments were carried out by creating specimens obtained from the mixture of: natural cement, water, citric acid (set retarder), rice straw and corncob. The decision to use a natural binder, rather than ordinary cement, is triggered by considerations on the environmental impacts linked also to the firing temperature.

The experimental phase was split into three tasks, based upon the type of aggregate used.

The first task involved obtaining the natural corncob with variable particle size (1-40 mm), containing pruning cuttings and an average humidity of 41%. When the drying was completed, an average humidity of 28% was identified along with a density of 155 kg/m^3. The initial analyses conducted on the mix designs highlighted cohesion issues linked to two factors: the non-uniform particle size and the non-quantifiable pruning cuttings. In the second task, specimens were produced with lower humidity (average 13%) in two different particle sizes (0.85-1.04 mm and 2-6.3 mm).

The results obtained in this phase highlighted a lack of cohesion due to the following factors: expansion and retraction of the plant aggregate as a result of its hygroscopic properties and lack of fibres.

Based upon the experiments that were conducted in the previous phases, to improve the cohesion of the industrialised corncob - natural cement mixture, the use of rice straw, chopped into stalks of 2-10 cm length, with average humidity of 15% and apparent density of 92.3 Kg/m^3, was trialled. The cohesion of the specimens was achieved by introducing plant fibre which filled up the cracks in the conglomerate.

Based upon the results achieved, a prototype was created on which the mechanical and technical performances were tested and the eco-compatibility of the production processes was assessed.

1.3.3 Testing and monitoring

From the compression tests carried out in the laboratory, according to the standards UNI EN 772-1:2015 and UNI EN 772-6:2002, on the 30-day specimens, average mechanical resistance R_{ck} was obtained of 0.5 MPa for 10% deformations. These values are equivalent to products present on the market (Biosys and Prespaglia), used as benchmarks, which use natural binders and hemp fibres.

The thermal behaviour was monitored according to the standards UNI EN 12664:2002 and UNI EN 12667:2002, with samples dried in the oven at a temperature of 50°C. The monitored thermal performances (U=0.29 W/m^{2}K) allow for the use of the prototype in different climatic areas.

1.3.4 Life Cycle Assessment

The eco-compatibility of the prototype was assessed using the LCA standard, from the extraction of the raw materials to the industrial gate of the prototype (Sarotto Group s.r.l.). The functional unit (f.u.) was 1 kg of product. The system boundaries (temporal, geographical and qualitative) for data were defined. In this case, data subsequent to 2010 and referring to the European Union were used, originating from direct (studies on the production phase) and indirect sources, obtained from databases (Cambridge Engineering Selector, Bousted Model and Ecoinvent). The calculation excluded contributions deriving from the water and citric acid, since their quantity was negligible with regard to f.u. (see figure 1.2).

The plant components (corncob and rice straw) were accredited a percentage of energies and impacts deriving from the principal cultivation (10%). The calculation of EE and EC relating to the plant components excluded land use, water consumption and emissions from the use of fertilisers and herbicides, while the feedstock energy and CO_2 absorbed by the plant were calculated (credit).

The transportations were calculated according to the standard UNI EN 16258:2013 and take account of the different types of trucks, their useful load and the different routes (hilly or flat). The production phase, for manufacturing 1 kg of product, involves the use of a standard cement mixer with hourly consumption of 0.042 kWh/kg.

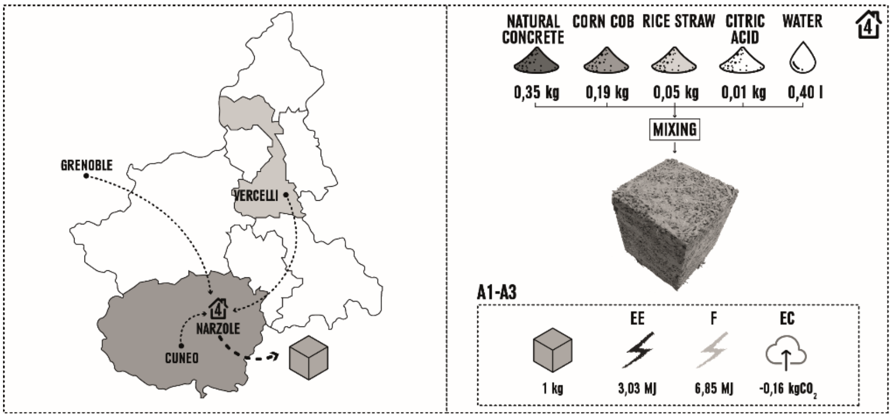

Figure 1.2. **On the left the network among the SMEs and agricultural suppliers; on the right, above, the raw materials and the secondary raw materials mixed for the ECOFFI manufacturing (1 kg), below, the accounting of the EE, the EC and the Feedstock Energy (F).**

The results of the study reveal that the production process with highest energy consumption and impacts (EE + EC) was linked to the production and transportation of natural cement while the processes on the agricultural by-products have low energy consumption and negative CO_2 values. Finally, also considering the production process hypothesis, the ECOFFI prototype can be assumed as an environmental friendly product (see figure 1.2) because of: the negative EC (ECOFFI is a carbon free product); the high Feedstock energy value (ECOFFI has a net calorific value potentially reusable in afterward recycling process).

1.3.5 Defining the supply chain and the industrial symbiosis process

To design the production chain for the by-products of corn and rice, the following were defined:

- Collection methods.
- Storage and drying methods.
- Available quantities.
- Average market prices.
- Modes of transport and distances.

In particular, as regards to corn, the collection and storage chain is already structured. Despite the annual product of corncobs in Piedmont being 182,475 t (ISTAT 2017 data), it is impossible to implement a collection chain for the whole available quantity. In this case the Consorzio Agricolo Piemontese per Agroforniture e Cereali (CAPAC) manages to collect 14,000 t of which 50% could be used for the construction industry, with annual availability of 7,000 t.

In the "short supply chain" perspective, Agrindustria Tecco (Cuneo, CN) was identified, a company equipped for storage, drying, sieving and sale of granules, at a distance of 43 km from the production site (Sarotto Group srl) of the ECOFFI prototype.The market prices of the industrialised corncob fluctuate between 26 -75 euro per bag of 20 Kg. Unlike corn, the rice straw supply chain is not structured, as farmers are not incentivised to collect the by-product.

To quantify the availability of by-product, a collection cycle was hypothesised every two years with a yield of 3 t/ha of dry matter (Sarasso 2007).

It follows that the annual availability in the Piedmont territory amounts to:

116,324 (ha) x 3 (t/ha) = 348,972 (t) : 2 (years) = 174,486 t

The supply chain was designed on a single pilot farm company and a straw-harvesting contractor. The amount of available useful hours, for collecting the straw, was estimated on the basis of ARPA (Regional Agency for the Environmental Protection) data, at 87 h/year. The contractor, considering an available quantity of 174,486 t of straw, using a single round baler is able to package 10 t/h. Out of 87 useful hours per year, it is able to produce 870 t/year, from which 15% has been deducted (movement between the various fields), to obtain a production of approximately 739.5 t/year. As regards the market, rice straw is listed on the price list of the Vercelli commodity exchange (2018) with an annual average value of 57.05 Euro/t.

1.3.6 Exploring the market

ECOFFI aims to enter the national and European market where there are already similar products, such as Biosys® and Prespaglia, both featured with low environmental impact technologies with high energy performances.

Table 1. Comparison between ECOFFI prototype and benchmarks.

Products	ECOFFI	Biosys	Prespaglia
Components	Prompt cement Corncob Rice straw	Prompt cement Hemp	Hydraulic lime Clay Wheat straw
Components Price (€/kg)[a]	0.44 – 1.10	0.45 – 0.57	0.16 – 0.18
Density (kg/m^3)	540	288	554
U (W/m^{2}K)	0.29	0.24	0.31
R_{ck} (N/mm^2)	0.5	>0.3	0.39
EE (MJ/kg)[b]	2.67	5.4	2.8
EC (kgCO_2/kg)[c]	-0.34	0.46	0.18

[a] The price refers to the production phase of the components, excluding transport.

[b] The Embodied Energy values were calculated for raw materials manufacturing (A1 – A2).

[c] The Embodied Carbon values were calculated for raw materials manufacturing (A1 – A2).

The comparative table (Table 1) shows that the ECOFFI prototype is the best in terms of mechanical resistance, EE and overall EC. The high price compared to the two benchmarks is due to the cost of corncob, which could significantly improve if economies of scale were created. In addition, to improve the density and thermal performances of the prototype, it will be necessary to implement the mix design.

1.3.7 Results

The project is still in progress. So far demonstrates the potential to recycling of agricultural by-products in the production of lightweight conglomerates.

ECOFFI can be used to create non-load bearing perimeter walls with thermal insulation function in various climatic areas, without the addition of further insulating materials.

However, further testing are needed to improve ECOFFI's performance (e.g. fire resistance) and to enable the transition from prototyping to production.

1.4 **Conclusion**

The outcomes of the research show that the use of agri-food waste in the construction sector - based on the principles of circular economy and systemic design/industrial symbiosis - is possible combining together sectors only apparently each other far. However, some aspects need to be taken into account as described in the previous paragraphs.

A fundamental aspect concerns the assessment of the availability of resources, which must be sufficient to guarantee a continuous supply and the economic sustainability of a new supply chain. It is necessary to consider that the availability of waste is affected by factors such as seasonality, the lack of a market that incentives companies to use waste, the small number of supply chains for collection and storage (CONCRICE). SMEs in the agri-food sector often do not have facilities for selecting, cataloguing and transforming waste material produced during the manufacturing stages (THERMALMOND). In Italy, many of the projects relating to the circular economy in construction are based upon initiatives of individuals and due to their fragmentary nature they are unable to pass from investigation to innovation by means of new products (KERATOSTONE). Some results from the LCA studies show that by-products recycling do not lead always to significant environmental advantages (CONCRICE and KERATOSTONE)

In a political framework that encourages and fosters the circular economy the lack of a regulatory framework and harmonised incentives that support companies in the search for solutions alternative to landfill disposal is also a major influence.

Gathering the different research projects in the ALL YOU CAN'T EAT cluster allows to correlate and compare the results, also partial, achieved in the described phases: concept; prototyping; monitoring; environmental assessment (LCA).

In this way, constraints and weaknesses analysed in a project become a scientific reference for the following one or an opportunity to define proper changes to a previous. This enables a continuing improvement and foster the transition from mere industrial research to the development of a product that can be launched on the market, in a relatively short period of time. In this scenario ECOFFI may considered a successful case study, in which: the reuse of by-products in the manufacturing system does not require the replacement of existing equipment; the mechanical as well as the physical performance is largely better than competitors; the environmental advantage (especially in terms of EC) is high enough to lay the conditions for a future environmental label.

Generally speaking, the experiences carried out in developing open recycling systems seems to lead to still partial successes, where it is not yet always possible to exploit the properties of a waste. The circular economy is certainly a non-negotiable medium to long term goal, with the awareness that a true industrial symbiosis requires the negotiation among flexibility of technologies, availability of secondary raw materials, product performance and tangible energy-environmental advantages.

Credits

This chapter is the result of a scientific work, carried out by the three authors and wrote with their equal commitment. Par. 1.3 was written in collaboration with Jacopo Andreotti and Denis Faruku.

Acknowledgements

We would like to thank:

For the CONCRICE project: Roberta Gariano; Dr Fulvio Canonico, Dr Manuela Bianchi (Buzzi Unicem). For the THERMALMOND project: Bruna D'Agata; Prof. Valentina Serra (DENERG, Politecnico di Torino); Dr Marco Dutto (Vimark). For the KERATOSTONE project: Mattia Sironi; Prof. Jean Marc Tulliani (DISAT, Politecnico di Torino); Globalcibo srl; Panamar snc; Keracoll spa. For the ECOFFI project: Jacopo Andreotti; Denis Faruku; Dr Marco Cappellari (Vicat Group) Dr Mauro Sarotto (Sarotto Group srl); Prof. Valentina Serra (DENERG, Politecnico di Torino); Mr Corrado Carbonaro (LASTIN, Politecnico di Torino).

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