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EXPERIENCING CIRCULAR DESIGN: STORIES OF AGRI-FOOD WASTE TRANSFORMED INTO NEW MATERIALS FOR ARCHITECTURE

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Abstract. The application of the Circular Economy model, supported by the European Commission, can be the driver of an industrial and architectural conversion and, also, an opportunity to innovate production processes through the elimination of the concept of waste. Furthermore, the attention of public and private actors as well as policies and rules are now focused on accelerating the ongoing transition from linear to circular economy.

In line with this multi-sectoral shift, the paper intends to illustrate the results of the research activities carried out at the Politecnico di Torino in cooperation with Small and Medium Enterprises (SMEs) of the Piedmont region (Italy).

In particular, the article illustrates a double experience developed with two different paths: the CIBUS' research project (Circular economy in the Building Sector from agri-food waste) and the innovative master's degree course Design and development the transition to the circular economy.

Both experiences apply circular economy approaches to grape, hazelnut, and wheat waste to understand whether they could be new "ingredients" for architecture and design.

Keywords: Agri-food waste, circular design, sustainable building products.

1. Introduction

In recent years, the circular economy (CE), based on the extension of the lifecycle of goods and the elimination of the concept of "waste", has attracted the attention of public and private actors – governments, academia, businesses – in that it is considered a development model alternative to the current model and on which to invest in. According to the Circular Economy Action Plan, the potential of the CE to tackle environmental challenges is considered to be significant in the built environment, due to its high impact [1]. Many authors claim that to fulfil the potential that the CE offers, a systemic change is needed in the way products, services, systems, and infrastructures are designed [2, 3]. This change produces a range of new challenges for architects and designers [4], relating to the design process in all its phases.

More specifically, circularity criteria may be applied to all the stages of building life cycles, as defined by Benachio et al. [5]: project design, manufacturing, construction, operation, end of life. For instance – in the manufacturing and end-of-life stages – one must plan the use of secondary and waste material [6] or at least material that is recycled and recyclable upon end-of-life [7].

In this context, the technology research group of the Department of Architecture and Design at the Politecnico di Torino, supported by Laboratorio Sistemi Tecnologici Innovativi (LaSTIn), has worked for several years together with SMEs for the development of technical elements and technologically advanced components and materials for architecture and design, and developed circular, short supply chains that may favour the development of local economies. In this regard, we hereby report the research, experimentation, and prototyping work related to the "All You Can't Eat" cluster for the valorisation of agri-food waste in the construction industry [8].

Growing food consumption and the consequent waste of agri-food products [9] may be considered opportunities, rather than threats, because the majority of such remainders may be potentially employed in numerous sectors, including construction. Agri-food waste may be used in thermal insulation [10], masonry [11], plaster [12] and concrete [13].

In this article, we intend to describe an ongoing experience whose goal is the reuse of agricultural waste from grapes, hazelnuts, and wheat as new resources for the construction sector and beyond. The interest in such waste and its potential implementation in different fields was indeed the occasion for the research group to network with three companies – a farm (Azienda Agricola F.lli Durando), a biomedical company (Nobil Bio Ricerche S.r.l.), and a construction material company (Sarotto Group S.a.s.) – located between the provinces of Asti and Cuneo and interested in experimenting circular processes with the purpose of – on one hand – triggering industrial symbiosis and – on the other hand – promoting local development.

(a). Vine shoots. (b). Stalks. (c). Pomace.

Figure 1. Three waste types of the grape production.

Piedmont Region		**Grape**	
Farmed area [ha]		43.872	
Quantity picked [t/year]		360.454	
Waste Type	Vine shoots	Stalks	Pomace
Percentage of end product [%]	/	4	15
Potential annual availability [t/year]	87.744	14.418	54.068

Table 1. Synoptic framework of the grape supply chain in Piedmont.

The experiment involved two closely correlated activities. The first activity – the CIBUS research project (CIrcular economy in the BUilding Sector from agri-food waste), a study performed in the context of the Bando Talenti della Società Civile promoted by the foundations Giovanni Goria and CRT – explored the implications of the circular economy model on the design of innovative interdisciplinary agricultural and construction processes. The second experience – the Design and development the transition to the circular economy course (master's degrees in Architecture for the Sustainability Design and in Systemic Design at the Politecnico di Torino) – an innovative activity between research and teaching, involved material transformation experiments using waste as "ingredients" and drawing new circularity scenarios to develop design concepts based on waste, recycled, or recyclable materials [14]. The paper focused, in particular, on the reuse of grape processing waste.

2. Methods

The research activity outlined hereinafter has been performed by the research group within the context of the All You Can't Eat cluster, through a consequential method of information analysis and processing. More specifically, the process involved three distinctive stages: analysis of the supply chains; analysis of potential valorisation of waste; identification of circular scenarios and preliminary experimentation.

2.1. Analysis of the supply chains: the grape supply chain

The analysis of the agricultural waste supply chains was conducted with a methodological approach to understand the common phases of "linear" production – thus not including material recovery and recycling processes: from the field, to the harvest, to processing, to the end product. A crucial step of this phase was the investigation of the waste-generating processes, with an identification of the potentially available types, percentages, and quantities. ISTAT (Italian institute of statistics) data, ENAMA (Italian body for agricultural automation) data, and data from scientific research were used as a reference to estimate the regional availability of waste based on average production of the end product.

Upon analysis of OIV (International organisation of Vine and Wine) data related to the grape supply chain in 2020, it was recorded that Italy is the top producer in the world [15] and Piedmont contributes 7 % of the national output [16]. Nevertheless, upon investigation of the supply chain processes, it was underlined how grape production is distinguished by a considerable quantity of by-products deriving both from the vine maintenance phase and from product processing (Table 1).

More specifically, three waste types were identified (Figure 1): vine shoots, stalks (4 %), and pomace (15 %). In the first case, the by-product is obtained from the annual vine maintenance operations, thus is pruning waste. Stalks are the result of crushing, which separates the grapes in bunches, and finally, the pomace is the mixture of the skin and seed residue from racking operations.

The data of vine shoots – related to the percentage of residue on the finished product – are not measurable because the by-products are produced by the common annual servicing practices, and they do not directly

(a). Brick.

(b). Paper.

Figure 2. Examples of pomace applications.

influence the amount of finished product.

Nevertheless, there is no generalized recovery and valorisation plan for such by-products. In fact, vine shoots are currently used as biomass for the production of energy, while stalks are used as soil amendments. As for pomace, it is the only by-product destined for recovery processes. According to Legge italiana n.238/16 [17], the by-product shall be supplied to distilleries or used as a soil amendment. Alternatively, it may be purified to obtain mixtures or molecules.

Therefore, modern uses of grape by-products contribute to reducing the waste quantity but are not a solution to the issue, because most of the waste is not employed in processes that promote their potential or extend their lifecycle.

2.2. Analysis of potential valorisation of waste: vine shoots, stalks, and pomace

The investigation of current supply chains has allowed an assessment of the annual waste production, but has also underlined the issue related to its management. In this regard, an exploration of the waste valorisation potential of waste has been conducted, considering the different areas of implementation, including construction and design. The investigation had the aim to identify examples of reuse and recycling that may be classified under two categories: on one hand, commercially available products and the solutions adopted; on the other hand, experimental material resulting from research studies. Tools used for such identification included virtual libraries (Matrec, Material Connexion, etc.) and the main scientific publishing platforms (ScienceDirect, Google Scholar, etc.).

As for grape waste, pomace is – given its high polyphenol and antioxidant content – the subject of international research. The extraction of such substances may favour the development of new human-use products in the pharmaceutical, cosmetic, and food sectors [18]. In the fashion sector, interesting experiments were conducted involving pomace for the production of technical biobased fabric [19]. Finally, a few examples in the construction field include a research study by the University of Parma for the use of pomace to manufacture hollow bricks [20].

The results of the investigation confirmed the limited valorisation of the vine-growing and winemaking supply chain by-products – mainly vine shoots and stalks – as well as the restricted research and experimentation behind recycling in the building sector.

2.3. Identification of circular scenarios and preliminary experimentation

The study and classification of materials and products were fundamental for the subsequent identification of reuse and experimentation scenarios.

Based on the exploration of waste valorisation potential, two activities were conducted in parallel.

The research was performed throughout the Design and development the transition to the circular economy course, and focused on the design of components for architecture and design, functional to the activities performed by partner companies of the project. The mix of architecture and design students from the Politecnico di Torino has allowed the visualization of new circularity scenarios and the development of design proposals involving waste material. The students presented interesting material concepts for construction and design use. In particular, it has been underlined how pomace may be used to produce: free-standing brick walls with the use of natural binding agents including beeswax; panels; and recycled paper. A few significant examples are outlined as follows (Figure 2).

For the CIBUS project, activities focused on the experimentation of new eco-friendly materials for architecture and design.

In relation to the winemaking and vine-growing supply chain, the research focused on the development

	Density [kg/m³]	Quantity [g]
CL90-S hydrated lime	500	162.24
Pomace	202.7	38.42
Rice straw	100	2.70
Water	1000	178.46

Table 2. Mix-design prototype 1.

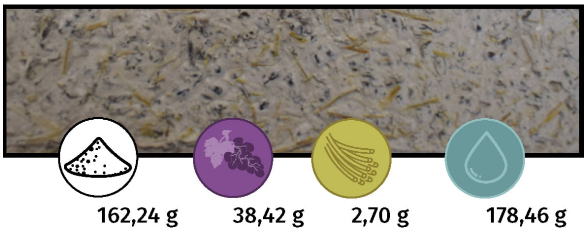

Figure 3. Prototype 1.

	Density [kg/m³]	Quantity [g]
NHL 3.5 lime	700	227.14
Pomace	202.7	38.42
Rice straw	100	2.70
Water	1000	159

Table 3. Mix-design prototype 2.

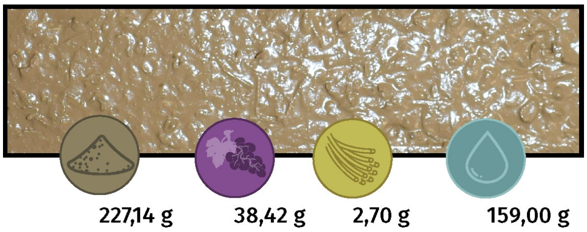

Figure 4. Prototype 2.

of two product types: lightweight plaster and wall panels.

The manufacture of lightweight plaster requires lightweight aggregates as identified by UNI EN 13055:2016 [21], standards, thus dried pomace was analysed to define apparent density (202.7 kg/m³). Once the lightweight aggregate classification was defined, a series of prototypes were made using pomace mixed with CL90-S hydrated lime and 3.5 natural hydraulic lime (NHL) as well as rice straw, used as a fibre to prevent crack formation events (Tables 2–3 and Figures 3–4).

As for the grape stalks, Medium Density Fibreboard (MDF) panels including the raw by-product – without the addition of adhesives or binding agents – were experimented with. The prototypes were produced with the application of a constant, 15-metric tonne load for 30 seconds. As done in previous research studies involving pressed panels of agricultural waste [22], the application of such load allowed the material to bind thanks to the lignin in the by-product, and form compact and homogeneous prototypes (Figure 5).

3. Results and Discussion

Performed within the Design and development the transition to the circular economy course, the concept designs by students represent a starting point for experimental activities. The prototypes are based on hypotheses backed by data from scientific literature – for instance, related to the performance features of waste products – and need to be verified and tested in laboratories. Experiments and proofs may be the subject of further study in experimental dissertations or research projects and feasibility studies in partnership with companies.

Within the CIBUS project, although the experimentation activity is still ongoing, the experiences related to lightweight plasters and MDF panels highlight opportunities and threats in the use of agricultural by-products for the production of technical elements for building and design.

In particular, cohesion issues have arisen in the lightweight plaster samples with pomace at the end of the drying process (28 days), given the features of the by-product employed. In fact, the by-product used for the tests was not a homogeneous material in terms of sizes and components (it included pomace, grapes, and stalks). Moreover, the content of organic material – in particular, the alcoholic residue from the vinification process – destabilizes the bond between by-product and binding agent, compromising cohesion. Therefore, further testing is required, possibly involving extraction of the waste material at a later stage – directly from distilleries or post-extraction of the molecules/mixtures.

As for the pressed grape stalk panels, results are encouraging, and prove that the material may be used in panelling for the architecture and design contexts. Despite the prototypes are comparable to MDF wood panels, the introduction of binding agents shall be considered in the performance of new experiments set to achieve better results.

The experiments highlight that the theories behind a circular economy in the building sector may be tangible and effective. Moreover, they demonstrate: on one hand, the importance of the designers' knowledge of such topics and their central role in design orientation, choices, and the anticipation of scenarios and solutions; on the other hand, the importance of experimental research in the design process.

Throughout the course, students had the opportunity to acquire knowledge in the interpretation of complex issues related to the transformation of waste into resources by means of design processes involving them in the first person. Furthermore, they developed a critical sense and the ability to design and develop circular economy scenarios, in close contact with real-life challenges requiring both global answers

(a). Pressing of stalks. (b). The prototype.

Figure 5. Experimental phase: the sample includes the raw by-product without the addition of adhesives or binding agents.

– promoted internationally – and local answers supported by the related tangible actions.

The experimental research – conducted in close contact with companies – outlined potential industrial symbiosis scenarios, and involved the design of virtuous processes in which the companies – operating in heterogeneous contexts – may plan to share waste, by-products, services, and know-how. Pursuing such corporate policies is functional to obtain significant economic and environmental advantages, and boosts the overall sustainability and competitiveness of production systems, simultaneously reducing industrial process waste and the demand for raw material.

4. Conclusion

The paper illustrates two experiences – an educational and a research experience, respectively – involving circular economy approaches in the design process and investigating whether agri-food waste can be a new "ingredient" for architecture and design.

The circular economy can be a driver of innovation and an opportunity for numerous sectors, including construction. In this perspective, the CIBUS research projects, as well as the activity performed throughout the Design and development the transition to the circular economy course are real examples of experimentation of circularity models, which confirm the growing interest by the scientific community in designing systemic models that foster the exchange of knowledge and material between different sectors.

They are also a clear sign of the new challenges that architects and designers will face in the future, such as the inclusion of possible reuse of waste or the environmental impact assessment of new processes and products based on secondary raw materials. They also show the new role that such subjects will need to play as "maestros" of the orchestra among the players, encouraging interdisciplinary design approaches.

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