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Supply Chains in Transition for the Development of Building Components: Three Educational Experiences in a Circular Economy Perspective

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Abstract: In line with the UN's 2030 Agenda for Sustainable Development, the circular economy may become an opportunity for change even in the construction industry, which is traditionally distinguished for its high resource consumption and considerable waste generation. Schools of architecture play a crucial role because the transition towards a circular economy implies the necessary development of new professional figures with wide-ranging skills that may pave the way for new directions in R&D. This article describes three different learning experiences developed at Politecnico di Torino, which have in common the prospect of supply chains in transition. In particular, it discusses the following: the transition of waste from the agrifood chain to the design sector through the experimentation of panels for furniture; the integration of local supply chains for cork, sheep wool, and soil through the design of insulation blocks and panels; and the 'as-is' transition of an element originally used as packaging from the agrifood supply chain to the building envelope component sector. These experiences show the possibility of hybridization between sectors that are only apparently distant from one other. Above all, they can be considered 'exercises' to train future architects in the experimentation and transformation of matter, systemic design, and divergent and lateral thinking for the development of new building materials and components.

Keywords: supply chains; circular design; reuse of waste; building components; learning experiences; education

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1. Introduction

Preventing the consumption and waste of resources is one of the top priorities of the European Union, in line with the UN's 2030 Agenda for Sustainable Development. Among the various business sectors, construction plays an important part in EU development plans, as it involves an above-average consumption of resources and waste generation [1].

As specified in the 2015 Action Plan for the Circular Economy [2] and confirmed in the new 2020 EU plan [3] and the Green Deal [4], the circular economy may become an opportunity for change even in the construction industry.

Promoting the abandonment of linear models of production and consumption—based on the production–consumption–disposal system—in favor of circular models where materials and products have more than one useful lifecycle means reducing landfill waste and increasing the recycling and reuse of materials [5]. Nevertheless, a deep change is necessary in this direction and in terms of how new materials and components are designed. Moreover, a new perspective on what is considered waste nowadays and what instead can be considered a resource is essential.

In this scope, schools of architecture must invest in new educational models that can prepare their graduates to become professionals aware of the challenges of the circular economy, able to design for product end-of-life, and capable of considering scrap and waste—not necessarily deriving from the construction industry—as new materials for architecture in an inter-sectoral perspective.

The main objective of this paper is to contribute to the nascent body of literature [5–7] on teaching the circular economy (CE) in higher education institutions by describing a few circular design experiences developed by Politecnico di Torino students as a part of their master's theses and aimed at presenting supply chains in transition where the waste of one sector becomes a resource for another.

The specific objectives of the paper are the following:

(1) To describe three different learning experiences, underlying experimental methodological approaches in the academic context that are suitable for the acquisition of useful skills to train new professionals to face the challenges of the circular economy;
(2) To identify possible research and development scenarios on transition supply chains, where waste becomes a resource in sectors only apparently distant from one another.

The experiences described here find a place in the debate on some central issues for the construction industry from a circular economy perspective: What skills must future architects develop, and how can they be accompanied throughout the education phase? What may the methodological approach in the development of such materials be? What 'new materials' may be included in architectural design?

The article is organized as follows: Section 2 refers to the requirement for new skills in higher education, with particular reference to architecture students, to deal with the transition from linear to circular models and introduces some educational experiences related to circularity conducted in the DAD; Section 3 describes three examples of circular economy education, highlighting the approach used, the context and reference chains, the methodology, and the summary of the research results (technical findings); Section 4 outlines the learning outcomes related to the three experiences; finally, conclusions are provided in Section 5.

2. Transition to Circular Economy: The Need for New Skills and Training in Higher Education

The transition towards a circular economy triggers brand-new processes with the purpose of responding to urgent challenges, including pollution reduction and lower resource consumption. This covers all dimensions—environmental, economical, political, and social—of sustainability and involves a variety of different stakeholders, including public and private individuals and professionals in different sectors and contexts.

The construction industry may strongly contribute to the passage from a linear to circular economy because it is able to absorb scrap/waste from the industry and from other supply chains, upcycle it, and extend its useful life in the scope of a carbon footprint reduction [8]. Numerous firms in the construction industry have leveraged the inter-sectoral 'contamination' and the design (or re-design) of products and supply chains based on waste materials. For instance, they produce thermal insulation panels with expanding polyurethane recycled from furniture, footwear, and automobile seats; thermal-acoustic panels based on recycled natural fiber from the textile industry and from textile goods that have reached their end-of-life; and rubber flooring made of recycled tires [9].

Examples of hybridization of the construction industry and other sectors can also be found in the literature. The use of textile waste in mortar and cement [10,11] and the reuse of agricultural waste in the production of bricks [12,13] have both been discussed.

In this context, the transition towards a circular economy implies the necessary development of new professionals with transversal skills that may define new R&D directions, connect networks of actors, and steer new processes. The traditional figure of the architect is joined by the architect/maestro—able to prefigure and lead new organizational, management, and production methods—and by the architect/R&D specialist with the ability to develop materials and parts based on the upcycling of waste.

In this scenario, higher education institutions play a critical role through teaching activities that inform new young generations and reskill professionals according to the new requirements of a CE [14,15]. Despite the overall CE literature being vast and the issue being introduced in many teaching programs [16], research on education for the CE is still somewhat limited, as the studies of Kirchherr and Piscicelli [5], Whalen et al. [6], and González-Domínguez et al. [7] highlight.

Moreover, Giannocchero et al., provide a picture of higher education for CE in Italy, highlighting the introduction of some programs, courses, and modules referred to different academic disciplines, mainly engineering, business, management, and chemistry, but they point out that there are still not many experiences in schools of architecture [17].

Starting from these premises, the article illustrates some experiences conducted in the School of Architecture of the Politecnico di Torino.

The technological research unit within the Department of Architecture and Design at Politecnico di Torino, in partnership with LaSTIn (Laboratory Systems for Technology Innovation), has been involved for many years in R&D activity related to new materials and products based on scrap and waste that is not necessarily from the construction supply chain but that may merge into the same. It has also performed educational activities to train architects to work in different areas and sectors, thus taking on new professional roles.

Some educational experiences refer to circularity using innovative teaching, adopting alternatives to frontal lectures and teacher-centered classrooms. For instance, the training activities of the Progettare e Sviluppare l'Economia Circolare (Design and Development of the Circular Economy) interdisciplinary module of the master's degrees in Architecture for Sustainable Design and Systemic Design focus not only on theoretical aspects but also on projects involving local entities (businesses, cultural organizations, social organizations) to explore the potential of promoting synergy and prototyping solutions, such that waste in one field may become a resource in another.

Other experiences included DIY workshops based on waste material in order to apply certain principles of circular design (reuse, repurpose, upcycling, design for disassembly) to real-life projects. Construction site waste, such as pallets, sawdust, beams, and nets, became furniture (Figure 1), and old wine barrels became micro-architectures in vineyards. By engaging students in hands-on experiences, they are more able to connect theories to real-world situations.

Figure 1. Example of hands-on experience carried out during a circular design workshop in collaboration with LaSTIn. The students made courtyard furniture with 0 km waste materials from a local construction site, becoming confident with equipment, connections, and reused materials.

3. Supply Chains in Transition: Three Examples of Circular Economy Education for the Development of Building Components

This paper presents three master's theses aimed at developing building components, which were selected because they approached the concept of transition in a circular economy perspective in different ways.

All of the theses have a common denominator: they explore the opportunities and criticalities of the circular economy in the passage from theory to practice.

The first experience proposes the transition of waste from the agrifood to the construction industry supply chain through lab experiments; the second experience investigates the integration of the cork supply chain in Sardinia with other local supply chains; the third experience presents—in a creative manner—the 'as-is' passage of a material used as packaging in the agrifood sector to the construction sector.

Below is a description of the three research studies, which were developed by placing the students 'at the centre'. In fact, each case study was selected considering the student's personal aptitudes and interests, educational background, and geographical context of origin. In this way, active involvement was fostered, knowledge of the local area and context was exploited, and contacts and direct relations with possible stakeholders were facilitated in order to improve research outcomes.

3.1. The Rice Supply Chain Meets the Natural Glue Sector and Generates Building Panels

The master's thesis *Da scarti agroalimentari a prodotti per l'architettura e il design: sviluppo di un pannello con lolla di riso* (From agrifood waste to architecture and design products: development of a rice husk panel) [18] was carried out using an experimental approach.

The experimental approach, associated with laboratory test procedures, allowed students to deal with variables to be controlled, to directly handle matter, and to test a new mix design with the aim of developing new materials and products and challenging traditional production processes.

The thesis was developed with Ricehouse, an innovative start-up company based in Biella and involved in research to find natural and sustainable materials for architecture, in particular by using rice production waste as a secondary raw material for the construction industry.

According to FAO data, world rice production is above 750 metric tonnes per year, spanning 160 million ha (just under 400 million acres) of farmed land. Italy is the biggest rice producer among European nations, boasting 230 thousand ha (just under 570 thousand acres) of farmed land.

Considering the farming phase—which generates stubble and straw—and the processing phase—generating byproducts such as husks/chaff—the rice supply chain produces tonnes of waste and byproducts that may, for the most part, be given new value, thus changing from cost (of disposal) to resource.

The research conducted in the thesis aimed to investigate in an experimental way creating—using strictly byproducts of rice production—panels for indoor use to replace built-in track changes function ones made of chipboard, plywood, or medium-density fiberboard (MDF). The research study primarily focused on the definition of a mix design that could guarantee appropriate performance in terms of cohesion and resistance using natural, formaldehyde-free adhesives that could allow recycling or composting of the material upon end-of-life.

Testing was conducted at the LaSTIn lab of the Department of Architecture and Design (DAD) at Politecnico di Torino. Three sampling campaigns took place, each involving different rice husk variants: full, untreated husks; full, treated husks; and crumbled husks.

Every campaign featured a series of tests with a variation of the inert material/binding agent ratio, the use of industrial starch adhesive or handmade rice starch adhesive, and with or without the addition of magnesite to the mix.

The results of each series yielded feedback to define the subsequent series, leading to gradual improvements in performance and a mix design, allowing better results in terms of cohesion and resistance.

Engaging in experimental research does not exclude theoretical and bibliographical research, market research, database analysis, and interpretation of regulatory requirements.

The experimental phase was anticipated, in fact, by an analysis of the goods on the market (e.g., MATREC database, www.matrec.com, accessed on 16 January 2020) and the investigation of the literature and standards.

Upon reviewing the selected papers related to previous studies and experimentation on the use of rice husks, the researchers found useful information on the treatment of husks and other parts, mix design, processing conditions, and sample sizes. A comparison of the qualitative and quantitative results achieved upon variation of the experiment parameters—with an assessment of their negative or positive influence on the final performance of the panels both in terms of mechanical resistance and in terms of thermal and soundproofing performance—was also made possible [19,20].

The research generated a feasibility study for a panel made strictly of waste and byproducts of the rice supply chain that might be used as chipboard or as the inner layer of sandwich panels with wooden face sheets (Figure 2).

Figure 2. Examples of the samples created in the experimental phase to define the mix design.

3.2. The Cork Supply Chain Meets the Other Products of Sardinia and Turns Them into Insulation Blocks and Panels

The second master's thesis, *Il sughero in edilizia: nuovi possibili scenari in Sardegna* (Cork in the construction industry: possible new scenarios in Sardinia) [21], was based on a systemic approach related to the creation of scenarios and networks of different entities.

In this context, the systemic approach relates closely to the territory, trying to activate a network of relationships between local production activities. The outputs of one supply chain become inputs for another, generating increased economic flow and new job opportunities. The context in which one operates is fundamental and a priority: local resources, people, culture, and materials are enhanced, and new opportunities are generated. This approach requires a very in-depth analytical phase in order to define possible scenarios.

The aim of the master's thesis was to propose new strategies for the promotion of the cork supply chain. Today, the latter is affected by strong limits in raw material production, and the integration with products from other local supply chains may be a winning strategy.

The will to implement an exemplary supply chain of the Sardinian tradition depends on numerous factors. Such a supply chain may become a key not only to relaunching the cork market but also to contributing to the promotion of the territory and, in particular, the hinterland that suffers from depopulation and abandonment. It may be a means to promote the know-how and culture belonging to local traditions.

In Italy, the cork industry is concentrated in Sardinia, where most of the cork processing companies are found. Ninety percent of the supply chain value is ascribable to corks, on which the entire industry has strategically focused, given its strict correlation to the winemaking and vine-growing sector. Nevertheless, there has been a decline in the supply chain in the past few years, with a consequent reduction in the numbers of companies and employees and an increase recorded only in the export of raw material. Such events are due to the economic crisis affecting Italy and Europe and, for the most part, the scarcity of raw materials [22,23].

The Sardinian cork supply chain thus needs to be modernized to offer competitive and innovative products on the market other than corks and, in parallel, make up for the lack of raw material.

These considerations inspire the research question: can cork be combined with other materials, giving life to composite materials that may be applied to different contexts, such as architecture?

A preliminary investigation of international scientific research was carried out to highlight how cork might be combined with other materials, such as natural fibers, polymers, and binding agents, that might improve material performance in terms of thermal resistance, soundproofing, and mechanical resistance.

The analysis was performed using the main search engines and scientific publication platforms (e.g., Google Scholar, ResearchGate, and Science Direct).

Research related to the use of expanded cork granules in combination with soil and cement [24,25] and the creation of products made of cork and other natural fibers [26] was particularly interesting for the purposes of this study.

It was also crucial to analyze the Sardinian region and try to combine the raw material—cork—with other readily available and local materials, thus designing possible new supply chains with the related production and economic—but even social and cultural—benefits.

The review of the international scientific literature allowed the researcher to focus on two specific materials, both available in Sardinia: soil and sheep wool. Soil is available, in particular, in the Campidano area (a valley between the provinces of Cagliari, Sud Sardegna, and Oristano), and sheep wool is an inexpensive natural fiber that is readily available and abundant regionwide.

Together with the desk research, the student carried out field surveys to identify stakeholders in the supply chain. In particular, an on-site analysis was conducted, with surveys and questionnaires addressed to the two fundamental actors in the field: the cork harvesters—who are the first figures coming into contact with the material—and the processing firms, which are an integral and major part of the production. In the surveys and questionnaires, the subjects underlined the issue related to raw material procurement and the need by cork oak owners to sell the product directly 'on the plant', thus transferring harvesting, transportation, and transformation costs to the buyers.

The analysis phase continued with an assessment of the specific steps of the production cycles with the related inputs and outputs, the identification of possible points of convergence, the estimate of the quantities required, the processes involved, and the possible target markets.

Two scenarios (Figure 3) that might lead to the creation of supply chains for specific composites with different performance and technology features based on cork in combination with local raw materials were thus identified. The first scenario involved the combination of cork granules and soil for the creation of blocks to use in the restoration of earth structures belonging to the cultural heritage. Sardinia hosts buildings made using the so-called ladiri, the popular traditional adobes used in Southern Sardinia and, in particular, in the Campidano area. The second scenario proposed the combination of cork granules and sheep wool to create insulation panels for new constructions or to renovate existing structures.

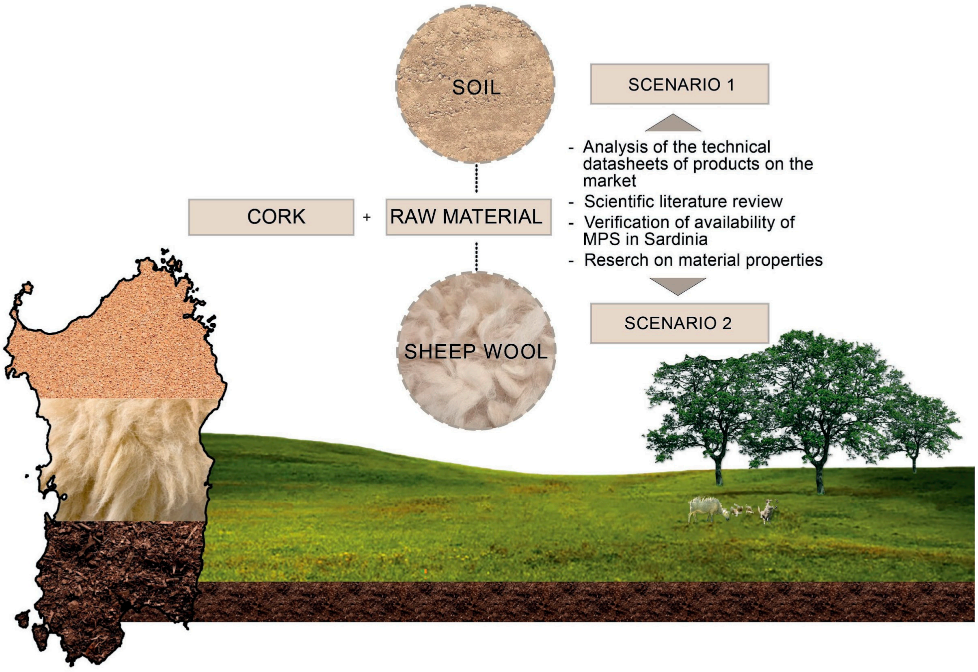

Figure 3. Summary of the scenarios identified and supply chains involved.

The two scenarios developed were aimed to suggest, at least theoretically speaking, solutions that might allow an improvement in the cork supply chain through the implementation of cork production, the creation of new supply chains, the stimulation of the business competitiveness of local industries, and the promotion of more sustainable raw material consumption. Nevertheless, the feasibility assessment of the new supply chains is strictly supported by data from scientific literature; thus, the scenarios built-in track changes function were limited by a lack of experimentation and were merely prerequisites for future investigation.

3.3. The Wooden Fruit and Vegetable Packaging Supply Chain Meets Roofing and Walling to Produce Building Envelope Components

The master's thesis *L'imballaggio ortofrutticolo in legno come risorsa per scenari di economia circolare in architettura* (Wooden fruit and vegetable packaging as a resource for circular economy scenarios in architecture) [27] investigated the reuse potential of wooden fruit/vegetable packaging upon end-of-life. The thesis adopted an approach with an alternation of logical thinking and creative thinking.

This approach required the integration of rational logic, based on facts, data, and information, with a logic based on intuition and creativity, allowing the student to develop divergent thinking capable of finding answers that were original and unusual but, at the same time, effective to a specific problem. Starting from a series of observations on the context of the problem, possible models and creative concepts were generated to be then validated with prototyping and testing.

The master's thesis identified new uses of the waste product 'as is'—without any transformation steps—in the architectural sector. In particular, the research study explored the possibility of giving new value and extending the useful life for a purpose other than the one it was designed for: from a used fruit and vegetable 'envelope' (a container) to a building 'envelope' (a modular element for walls and roofs).

The study was brought about with the support of CAAT, the largest agrifood wholesale center of Turin, where tonnes of fruit and vegetables are brought to and bought by retailers selling in the street markets of the Piedmont region and beyond. CAAT offered availability to interview its operators and perform visits to better understand the different kinds of packaging, the quantities handled, and the waste management methods. It was recorded that wood is the main waste type among containers (plastic, cardboard, and wooden crates) used by wholesalers, retailers, etc., to transport and sell fruit and vegetables. Wooden crates are more popular than plastic crates because of their lower cost and their greater performance in terms of preservation (rotting prevention) in the summer.

The substantial consumption of wooden packaging was confirmed on a national level: in 2021, an estimated 3.1 tonnes of such packaging was used in Italy (https://www.rilegno.org/rapporto-rilegno-2021/, accessed on 7 June 2023).

Nevertheless, the same report states that nearly 2 million tonnes of such wood packaging were destined for recycling or incineration, abundantly exceeding the reuse goals set by the European Union (Directive (EU) 2018/852).

The researcher developed an analytical phase and a propositional phase.

Direct observation made it possible to establish the dimensions and characteristics of the wooden fruit, its elements, and how they were assembled.

The analysis of the state-of-the-art and the scientific literature were fundamental for the investigation of the reuse possibilities for the waste material and allowed the researcher to identify related past projects and experiments.

Wooden fruit and vegetable packaging is not a newcomer in the world of architecture and design. For instance, the library at the Tlaxiaco Institute of Technology in Ejutla, Mexico, hosts wooden crates used as bookshelves and as openings in the building envelope for ventilation purposes [28]. Moreover, the Poland pavilion designed for Expo 2015 featured outer walls made of apple crates as a visual reference to one of the nation's agricultural specialties. Finally, the *Lobelia color dell'aere* installation created in Rome in 2011 for the Festival del Verde e del Paesaggio (greenery and landscaping festival) featured fruit crates as the walls of a roofless room containing little flowers.

Generally speaking, upon reviewing the projects implemented, it was recorded that wooden crates were used mostly as furniture or in art installations, with only a few exceptions in the construction sector—mainly in self-build and temporary structures.

Nevertheless, a few experimental studies suggested the potential of wooden fruit and vegetable packaging in the construction industry to replace other modular elements.

In particular, the literature recurrently included applications of such packaging as a technical element in walling [29–32] and roofing [33–36].

The aforementioned investigations allowed the researcher to adjust the subsequent propositional step aimed at developing a series of concepts. Two-part datasheets were thus drafted: the first, analytical part underlined the fields of application, the materials used, and the results of the related tests; the second, propositional part described possible alternative concepts compatible with an 'as-is' use of wooden crates.

Although the research must be extensively completed—with the testing and validation of new components as well as the systemic design of potentially new supply chains, to mention a couple—it has allowed a preliminary reflection on the alternative use of a waste product and its 'as-is' use in the architectural context.

The results of the thesis include a wide range of proposals that emerged both in terms of wall components and envelope components. The assembly methods chosen in each proposal were analyzed to shift the focus from the individual element to the system.

The image (Figure 4) shows an example of a proposal: a modular component for a green roof, where the wooden crates act as containers for the layered system.

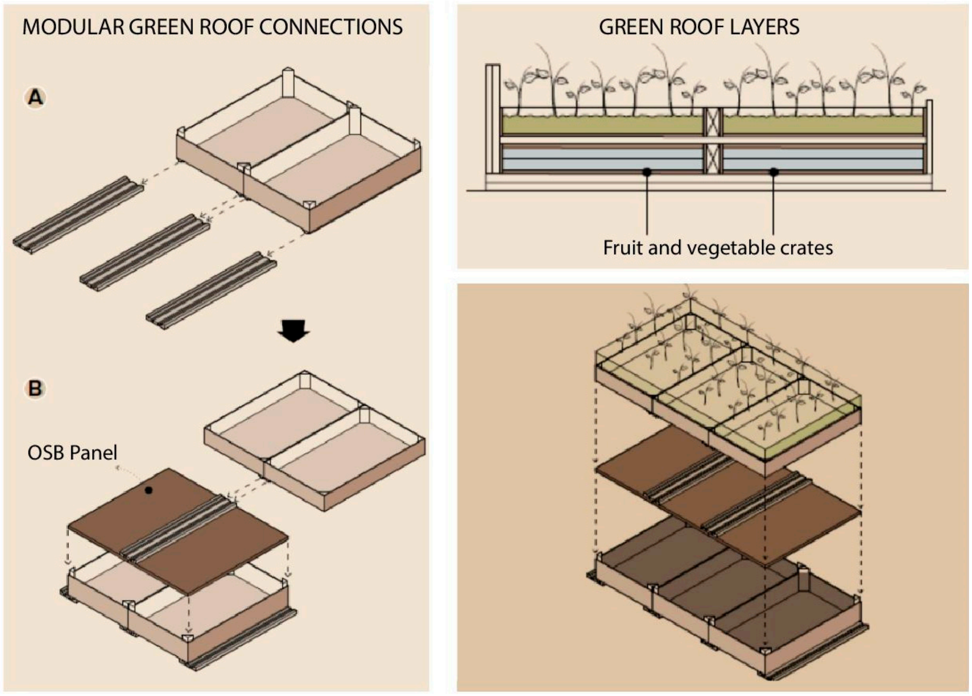

Figure 4. Example of concept design for a modular green roof, including the reuse of fruit and vegetable crates. On the left, the assembly steps: (**A**) horizontal connections; (**B**) vertical connections.

4. Results and Discussion

The examples provided—whose results must be considered partial in comparison to a process leading to the materialization and marketing of an original idea—show the potential for contamination and transition between different production chains that are relevant from an educational and training perspective. They underline how it is possible to raise curiosity (interest) in the students on topics related to circular design and stimulate a change in perspective. They encourage a research-based approach that—in relation to the different goals and research areas—may be expressed in different ways (following different strategies and work methodologies).

The first experience was carried out using an experimental approach. Experimental theses show that laboratory research is essential for the realization of new materials and the activation of innovative processes. Through experimentation, the researcher's intuition takes shape, characteristics and performance can be verified, and the work can lead to unexpected research paths: theories can be tested for further investigation or be abandoned.

The learning outcomes resulting from the application of these methods and tools (e.g., study of data from literature reviews, inventory of products on the market, use of databases and material libraries, mix design and sample preparation, assessment of properties) were the following: to identify opportunities for the valorization of waste from different sectors, to design new products from waste, to experiment with material transformation processes, and to prototype solutions to verify the feasibility of the project.

The second master's thesis was based on a systemic approach, starting from a specific territory and its resources to develop new networks and supply chains.

In order to be able to define plausible scenarios, the accuracy of the analytical phase is crucial in order to have a broad and detailed picture of the reference context, available resources, and stakeholders.

The learning outcomes derived from the application of these methods and tools (e.g., scientific literature review, field surveys and interviews, verification of the availability of local resources, identification of supply chain stakeholders) were as follows: the exploration of the possibilities of activating CE processes within real, local contexts, to design circular and sustainable supply chains, and to evaluate and compare different scenarios.

The third master's thesis adopted an approach with an alternation of methodological approaches, at times based on convergent and logical/analytical thinking and sometimes based on divergent and creative thinking. This approach allows students to develop analytical abilities and, at the same time, creative abilities involving aspects of intuition and emotion; the combination of these skills enables them to 'think outside the box' and identify innovative solutions.

The learning outcomes resulting from the application of these methods and tools (e.g., study of the material through direct observation, investigation of reuse possibilities through desk research, alternation of logical and creative thinking) were the following: understanding and managing the design challenges related to the reuse of waste 'as is' in the building sector and rethinking the building product to decrease impact and promote circularity.

In the three experiences described, the application of circular economy techniques for the design and development of building components is appropriate for implementing and improving the analytical capacity of different circular economy strategies. This confirms the advantages of implementing the teaching of the circular economy throughout university education, completing the student training in sustainability.

Using an innovative, experiential, and 'doing' approach that goes beyond conventional teaching methodology (primarily based on the transmission of knowledge) students acquire both technical skills directly linked to professional practice and abilities of a transversal nature, linked to the development of soft skills and the creation of an active and engaged citizenship.

It is important to emphasize that these three case studies, although circumscribed with respect to the broad theme of the circular economy, represent a step forward in schools of architecture, where this approach is not so obvious and widespread and where students generally do not find many opportunities in the educational curriculum to challenge with in-field learning in a circular economy perspective.

5. Conclusions

The experiences described in this paper aim to be a part of the debate on some relevant issues from the circular economy perspective.

What skills must future architects develop, and how can they be supported in their training path?

Professionals today and ones of the future are asked to have increasingly transversal skills spanning every work field, including architecture.

The experiences outlined may be considered 'exercises' to train future architects to acquire experimentation and material transformation skills, a systemic view, and divergent, lateral thinking.

Such training allows them to acquire multidisciplinary skills, thus thinking of as many solutions as possible to the same problem, multiplying their ideas to more easily combine them in new ways, and abandoning obvious and consolidated concepts to develop new ones. Schools of architecture thus have an important role in training versatile figures, where the architect is joined by the architect/maestro—able to prefigure new scenarios and explore possible synergies among different actors—and by the architect/R&D specialist—with the ability to identify possible R&D paths based on the upcycling of waste.

What might be the methodological approach in the development of such materials?

The cases described underline different methodological approaches to the design of new components for architecture: the first method is experimental, including hands-on activities and mix design; the second method is systemic and involves the development of different scenarios and networks of actors; the third method is in part logical/analytical, in part creative, and based on the concept of multiple solutions.

What 'new' materials may be included in architectural design?

In spite of the limitations and possible paths yet to be explored in terms of feasibility, the case studies prove the possible contamination between industrial sectors and the potential transition between supply chains that are only apparently distant. They confirm that the construction industry may embrace waste material at different stages—from material/component manufacturing to construction and implementation—from other sectors by recycling them or even reusing them in completely different ways from their original function.

The experiences described, although limited in the number of cases presented, are part of the emerging debate on the teaching of CE. They are intended to be a stimulus for a discussion on new ways of teaching (and learning) in higher education, which help students acquire new skills, abilities, and consciousness referring to the CE challenges.

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References

1. Sáez-de-Guinoa, A.; Zambrana-Vasquez, D.; Fernández, V.; Bartolomé, C. Circular Economy in the European Construction Sector: A Review of Strategies for Implementation in Building Renovation. *Energies* **2022**, *15*, 4747. [CrossRef]
2. European Commission. *Closing the Loop—An EU Action Plan for the Circular Economy*; European Commission: Brussels, Belgium, 2015; COM614 Final. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52015DC0614 (accessed on 20 June 2023).
3. European Commission. *A New Circular Economy Action Plan for a Cleaner and More Competitive Europe*; European Commission: Brussels, Belgium, 2020; COM98 Final. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN (accessed on 20 June 2023).
4. European Commission. *Il Green Deal Europeo*; European Commission: Brussels, Belgium, 2019; COM640 Final. Available online: https://eur-lex.europa.eu/legal-content/IT/TXT/?uri=COM%3A2019%3A640%3AFIN (accessed on 20 June 2023).
5. Kirchherr, J.; Piscicelli, L. Towards an education for the circular economy (ECE): Five teaching principles and a case study. *Resour. Conserv. Recycl.* **2019**, *150*, 104406. [CrossRef]
6. Whalen, K.A.; Berlin, C.; Ekberg, J.; Barletta, I.; Hammersberg, P. 'All they do is win': Lessons learned from use of a serious game for Circular Economy education. *Resour. Conserv. Recycl.* **2018**, *135*, 335–345. [CrossRef]
7. González-Domínguez, J.; Sánchez-Barroso, G.; Zamora-Polo, F.; García-Sanz-Calcedo, J. Application of circular economy techniques for design and development of products through collaborative project-based learning for industrial engineer teaching. *Sustainability* **2020**, *12*, 4368. [CrossRef]
8. Munaro, M.R.; Tavares, S.F.; Bragança, L. Towards circular and more sustainable buildings: A systematic literature review on the circular economy in the built environment. *J. Clean. Prod.* **2020**, *260*, 121134. [CrossRef]
9. Carbonaro, C.; Giordano, R.; Andreotti, J.; Faruku, D. Approccio circolare per l'innovazione tecnologica con scarti della filiera agroindustriale. *Techne* **2021**, *22*, 208–217. [CrossRef]
10. Gonilho-Pereira, C.; Faria, P.; Fanguerio, R.; Martins, A.; Vinagre, P.; Rato, S. Performance Assessment of Waste Fiber-Reinforced Mortar. *Mater. Sci. Forum* **2012**, *730*, 617–622. [CrossRef]
11. Fantilli, A.P.; Sicardi, S.; FDotti, F. The use of wool as fiber-reinforcement in cement-based mortar. *Constr. Build. Mater.* **2017**, *139*, 562–569. [CrossRef]
12. Faustino, J.; Silva, E.; Pinto, J.; Soares, E.; Cunha, V.M.C.F.; Soares, S. Lightweight concrete masonry units based on processed granulate of corn cob as aggregate. *Mater. Construcción* **2015**, *65*, e055.
13. Pinto, J.; Vieira, B.; Pereira, H.; Jacinto, C.; Vilela, P.; Paiva, A.; Pereira, S.; Cunha, V.M.C.F.; Varum, H. Corn cob lightweight concrete for non-structural applications. *Constr. Build. Mater.* **2012**, *34*, 346–351. [CrossRef]

14. Vicente, J. Product design education for circular economy. In *Advances in Industrial Design, Proceedings of the AHFE 2020 Virtual Conferences on Design for Inclusion, Affective and Pleasurable Design, Interdisciplinary Practice in Industrial Design, Kansei Engineering, and Human Factors for Apparel and Textile Engineering, San Diego, CA, USA, 16–20 July 2020*; Springer International Publishing: Berlin/Heidelberg, Germany, 2020; pp. 519–525.
15. Neto, V. Eco-design and Eco-efficiency Competencies Development in Engineering and Design Students. *Educ. Sci.* **2019**, *9*, 126. [CrossRef]
16. Ellen MacArthur Foundation. *A Global Snapshot of Circular Economy Learning Offerings in Higher Education*; Ellen MacArthur Foundation: Cowes, UK, 2018. Available online: https://indd.adobe.com/view/a76263e6-f75f-4f12-bbdc-920c01f42c6f (accessed on 25 September 2023).
17. Giannoccaro, I.; Ceccarelli, G.; Fraccascia, L. Features of the higher education for the circular economy: The case of Italy. *Sustainability* **2021**, *13*, 11338. [CrossRef]
18. Giaccone, G. Da Scarti Agroalimentari a Prodotti per L'architettura e il Design: Sviluppo di un Pannello con Lolla di Riso. Master's Thesis, Politecnico di Torino, Torino, Italy, 2020.
19. Ciannamea, E.M.; Ruseckaite, R.A.; Stefani, P.M. Medium-density particleboards from modified rice husks and soybean protein concentrate-based adhesive. *Bioresour. Technol.* **2010**, *101*, 818–825. [CrossRef] [PubMed]
20. Belloni, E.; Buratti, C.; Lascaro, E.; Merli, F.; Ricciardi, P. Rice husk panels for building applications: Thermal, acoustic and environmental characterization and comparison with other innovative recycled waste materials. *Constr. Build. Mater.* **2018**, *171*, 338–339.
21. Manca, A.M. Il Sughero in Edilizia: Nuovi Possibili Scenari in Sardegna. Master's Thesis, Politecnico di Torino, Torino, Italy, 2021.
22. Cutini, A.; Muscas, F.; Carta, V.; Casula, A.; Dettori, S.; Filigheddu, M.R.; Maltoni, S.; Pignatti, G.; Romano, R. *Analisi e Proposte per la Valorizzazione della Sughericoltura e della Filiera Sughericola Italiana*; Rete Rurale Nazionale, Consiglio per la Ricerca in Agricoltura e L'analisi Dell'economia Agraria: Rome, Italy, 2019.
23. Dettori, S.; Filigheddu, M.R. Il sughero in enologia. Analisi della filiera nazionale. *L'Italia For. Mont.* **2017**, *71*, 331–343.
24. Correia-da-Silva, J.; Pereira, J.; Sirgado, J. Improving rammed earth wall thermal performance with added expanded granulated cork. *Archit. Sci. Rev.* **2015**, *58*, 314–323. [CrossRef]
25. Guettala, S.; Bachar, M.; Azzouz, L. Properties of the Compressed-Stabilized Earth Brick Containing Cork Granules. *J. Earth Sci. Clim. Change* **2016**, *7*, 353. [CrossRef]
26. Gil, L. Cork: Sustainability and new applications. *Front. Mater.* **2015**, *1*, 38. [CrossRef]
27. Orlando, E. L'imballaggio Ortofrutticolo in Legno Come Risorsa per Scenari di Economia Circolare in Architettura. Master's Thesis, Politecnico di Torino, Torino, Italy, 2020.
28. Bahamòn, A.; Sanjinés, M.C. *Rematerial. From Waste to Architecture*; W.W. Norton & Company: New York, NY, USA, 2010.
29. Galbrun, L.; Scerri, L. Sound insulation of lightweight extensive green roofs. *Build. Environ.* **2017**, *116*, 130–139. [CrossRef]
30. Bates, A.J.; Sadler, J.P.; Greswel, R.B.; Mackay, R. Effects of recycled aggregate growth substrate on green roof vegetation development: A six year experiment. *Landsc. Urban Plan.* **2015**, *135*, 22–31. [CrossRef]
31. D'Orazio, M.; Di Perna, C.; Di Giuseppe, E. Green roof yearly performance: A case study in a highly insulated building under temperate climate. *Energy Build.* **2015**, *55*, 439–451. [CrossRef]
32. Dvorak, B.; Volder, A. Rooftop temperature reduction from unirrigated modular green roofs in south-central Texas. *Urban For. Urban Green.* **2013**, *12*, 28–35. [CrossRef]
33. Mathis, D.; Blanchet, P.; Lagière, P.; Landry, V. Performance of Wood-Based Panels Integrated with a Bio-Based Phase Change Material: A Full-Scale Experiment in a Cold Climate with Timber-Frame Huts. *Energies* **2018**, *11*, 3093. [CrossRef]
34. Pavelek, M.; Prajer, M.; Trgala, K. Static and dynamic thermal characterization of timber frame/wheat (*Triticum aestivum*) cha thermal insulation panel for sustainable building construction. *Sustainability* **2018**, *10*, 2363. [CrossRef]
35. Latif, E.; Ciupala, M.A.; Tucker, S.; Wijeyesekera, D.C.; Newport, D.J. Hygrothermal performance of wood-hemp insulation in timber frame wall panels with and without a vapour barrier. *Build. Environ.* **2015**, *92*, 122–134. [CrossRef]
36. Carbone, C.M. Mainstreaming Straw as a Construction Material: Understanding the Future of Bio-Based Architectural Materials. Ph.D. Thesis, Massachusetts Institute of Technology, Cambridge, MA, USA, 2003.