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"Gheorghe Asachi" Technical University of Iasi, Romania

REMODEL: CIRCULAR COMPOSITE MATERIALS DESIGN FOR A SUSTAINABLE INNOVATION OF MADE IN ITALY

Romina Santi[1*], Sara Valassina[1], Marco Arioli[1], Andrea Marinelli[1], Chiara Del Gesso[2], Carmen Rotondi[2], Barbara Del Curto[1], Sabrina Lucibello[2], Mariapia Pedeferri[1]

[1]*Department of Chemistry, Materials, and Chemistry Engineering, Politecnico di Milano, Italy*
[2]*Department of Planning, Design, Technology of Architecture, Sapienza Università di Roma, Italy*

Abstract

The transition to a circular economy requires concrete strategies to transform waste into resources within production systems that are as local as possible. The 3F sectors: Food, Fashion, and Furniture, pillar of *Made in Italy*, generate waste streams that are often undervalued despite their high intrinsic potential. The REMODEL project, funded by the Italian National Recovery and Resilience Plan, explores how Italian excellence can embrace circularity by transforming scraps into innovative materials and products for circular productions. The goal is contributing to the debate on material and design-driven strategies for the circular economy in the 3Fs and to analyze the methodological and experimental outcomes in terms of material innovation and stakeholder involvement. The underlying hypothesis is that design can act as a catalyst to integrate waste recovery processes into local production systems, generating cross-sector synergies and new models of circular competitiveness. To do this, REMODEL has traced waste flows from regional excellences in Lombardy and Lazio, analyzing their potential and developing circular composite materials. The research has combined analysis and experimentation in the laboratory with co-design and prototyping practices in Open Labs. The research activity has developed new materials and prototypes, demonstrating technical feasibility and industrial relevance. The methodology adopted has condensed the experimentation, facilitated the exchange of materials between sectors, and allowed companies to concretely evaluate the applicability of new materials. The project proposes a replicable and scalable circular innovation model capable of generating territorial value and opening perspectives for circular production on a regional scale.

Key words: circular composite materials, circular economy, design-driven material, made in Italy

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1. Introduction

The transition to a Circular Economy (CE) requires enterprises to reorganize manufacturing according to sustainability principles (Geissdoerfer et al., 2017, Loiseau et al., 2016; Prendeville et al., 2014). However, the transition requires significant economic investments due to the intensive "recirculation of resources in loops of reuse" (Bassi, 2017; Hobson, 2020). Processes of material renewal and recycling are necessary (Clark et al., 2016), but they are often difficult for small and medium-sized enterprises to afford. Although some best practices highlight a symbiotic networking strategy between companies to address the transition to a circular economy, this new economic model still seems to be poorly understood. It lacks a well-defined methodology and the necessary tools to be implemented in companies and even in society (De Jesus and Mendonça, 2018). A new form of relation, engagement, and discovery of the territory is needed to effectively get a territorial interest in the CE (Bonomi and De Rita, 1998; Magnaghi, 1998).

Design, materials and industrial economy experts, along with sociologists, can stimulate social creativity (Fischer, 2013) as a source of real

[*] Author to whom all correspondence should be addressed: e-mail: romina.santi@polimi.it; Phone: +39 02 23997816

innovation. This would offer an attractive alternative to recover material waste, not only as a technological challenge but as a resource linked to territorial identity, social sustainability, and inclusivity (Horizon Europe Pillar 2 - Global Challenges and European Industrial Competitiveness Cluster 2).

Coherently to SDG 12 of Agenda 2030 (SDGs, 2015) this research focuses on waste reduction across the various production stages. The Waste Framework Directive 2008/98/EC directive defines waste as "*that substance which the holder discards or has decided or is obliged to discard*" (EC Directive, 2008). In this work, all substances used in the generation of new circular composite materials will therefore be referred to as waste or scraps.

Starting by looking at waste as a resource, it is possible to value it while bringing value to local realities, as suggested within the 2030 Agenda. According to the European Green Deal and the Circular Economy Action Plan, the connection between CE and territories is crucial since a resource-efficient model delivers social objectives. In Italy, local and regional territories have a suitable scale to close resource loops, generating a sustainable circular ecosystem, and designing participatory community-based schemes. Moreover, Italy has always played a fundamental role in the research and practical application of raw materials in successful products, which, above all, have characterized its identity. The innate inventive capacity of Italian design has been able to "modify the sensitivity of the human race" (Kubler, 1962). This is not only deployed in aesthetics but also in imagination, defining new uses, functions, and languages. In recent years, many Italian start-ups and companies have adopted a circular approach, focusing on the recovery and valorization of industrial waste for the development of innovative green materials. One example is Orange Fiber® (https://orangefiber.it/it/), which has patented a method to extract cellulose from citrus waste and transform it into a biodegradable fiber.

Given this background, this manuscript presents the REMODEL project within the broader framework of post-COVID-19 recovery strategies under the Italian National Recovery and Resilience Plan agenda. The project aims to graft new opportunities for Italian production system, starting from the three emblematic sectors of Made in Italy, the so-called 3Fs: Furniture, Fashion, and Food. Conducted by two research units (RUs) at Politecnico di Milano and Sapienza Università di Roma, the project focuses on Lombardy and Lazio, two regions that include industrial excellences and represent potential testing territories for circular innovation.

The aim of this article is therefore twofold: (i) to illustrate how REMODEL contributes to the debate on design-driven strategies for CE in the 3Fs sectors; (ii) to explore the methodological and experimental outcomes of the project in relation to material innovation and stakeholder engagement. The underlying hypothesis is that design can act as a catalyst to integrate waste valorization processes into local production systems, generating cross-sectoral synergies and fostering new models of sustainable competitiveness. Accordingly, the article addresses the following research questions:

- How can territorial waste flows mapping and analysis highlight new opportunities for CE-oriented business models?
- To what extent can design-driven methodologies support the development of Circular Composite Materials (CCMs) that are both technically viable and culturally resonant within the Made in Italy context?
- What role can co-design practices, such as Open Labs, play in bridging research and industry, fostering the acceptance and diffusion of new circular materials?

2. Material and methods

A comprehensive description of the methodology employed is provided below, beginning with the territorial mapping of enterprises, waste production, and virtuous activities and practices related to material use, enlightening new economic opportunities within a CE-oriented approach. The analysis, focused on territorial excellences, strives to create virtuous transcultural cycles within the 3Fs, envisioning the recirculation and reuse of material waste in local production systems, building possible synergies between research and industry. During the early experimental phase of the project, two distinct methodologies were adopted by the RUs: a design-driven and a material-driven approach, each with its own epistemological foundation and operational logic.

The design-driven approach (Buchanan, 1992; Ferrara, 2021; Verganti, 2009) starts from the definition of a product or specific need. Material experimentation is therefore directed toward achieving the properties required by the intended application. This convergent method ensures alignment with market and production constraints, but tends to limit exploratory thinking and lateral innovation. Complementarily, the material-driven approach originates from the properties of the waste material itself, embracing open-ended experimentation detached from specific applications. Grounded in concepts such as material agency and material experience (Giaccardi and Karana, 2015; Karana et al., 2015), this method promotes discovery and creativity through hands-on exploration, but often struggles to generate outputs that are readily translatable into real-world scenarios.

As a result, a hybrid and reflective methodology was determined to combine the design-driven approach's application-oriented focus with the material-driven approach's exploratory potential.

2.1. Territorial analysis: from markers of excellence to waste identification

The first phase aims to create an extensive inventory of waste sources related to the 3Fs, establishing a foundation for subsequent project phases and highlighting potential areas for design intervention. The territorial analysis includes the following steps:

- **Excellence Markers Identification:** In the Food sector, these markers correspond to certifications ensuring the protected and controlled origin of the final product, establishing it as a regional excellence of Made in Italy. Research was conducted using regional certified sources listing these markers and associated products. Made in Italy certifications regulate production methods and companies rather than finished products for the Fashion and Furniture sectors; therefore, the analysis considered local consortia promoting regional manufacturing as indicators of excellence.
- **Marked Excellences Recognition:** Regional products or manufacturers that possessed at least one of the previously identified markers were selected from relevant lists (e.g. IGP- Protected Geographical Indication, DOC- Controlled Designation of Origin) and subsequently mapped to the province(s) where they are present.
- **Waste Identification:** Using white and grey literature (Brennan and Browne, 2021; Cordella and Hidalgo, 2016; Nordås, 2004), the key stages of the supply chains were identified. This was limited to one supply chain for each F, and shared among all companies of that specific F, regardless of the specific excellence considered. The stages with the highest waste generation potential were highlighted. Next, companies were mapped within the catalogued excellences, focusing on their role in the supply chain. Finally, territorial scraps were categorized based on thematic relevance and seasonal availability, and potential suppliers were identified.

2.2. Pilot waste reframing

Once the scraps from the 3Fs excellences were identified, the second phase of the research focused on supporting ideation processes by identifying best practices for the valorization of waste resources. This phase involved defining materials and methods for experimental activities aimed at the production of CCMs. This phase is subdivided into the following steps:

- **Waste validation and stakeholder interviews:** Companies identified during the territorial recognition phase were engaged through targeted interviews to explore application opportunities for the developed materials within their existing production processes. The objective was to identify entry points for CCMs integration, validating the mapped wastes and their actual seasonality, availability, and existing upcycling or downcycling practices while verifying stakeholder interest and constraints.

This activity also aimed to identify potential applications that could fill specific gaps within the original waste's production chain, thereby enhancing the circularity and potential value recovery of the material itself.

- **Extensive literature review:** A thorough analysis was conducted for all selected scrap with a focus on identifying their specific properties relevant to composite applications. A review of both white and grey literature was carried out, examining the morphologies and types of materials developed from these scraps, as well as the substances used, processing techniques employed, and potential applications explored.
- **Brainstorming and co-design:** Collaborative workshops and discussions were conducted among design and engineering experts, focusing on comparing waste recovery practices and exploring strategic pathways to integrate CCMs into the 3F sectors. Following a design-driven approach, co-design sessions were guided by literature analysis and companies' needs identified during the interviews. These sessions aimed at envisioning products' concepts fostering new economic opportunities, supporting local companies and communities across various production contexts, and driving future innovation.
- **Material development:** After defining the laboratory activities required for the development and characterization of CCMs, the experimentation began outlining the material requirements, selecting appropriate methods, and establishing a structured experimental plan to follow. In order to enhance sustainability, the approach focuses on the use of bio-based substances and the optimization of waste material quantities employed, together with low-tech manufacturing processes to assess the replicability and technological transfer.

2.3. Strategies for innovation: shared methodology and open labs

Based on the previous phases, especially the insights gathered during *Waste validation and stakeholder interviews*, the Open Labs were structured around a cyclical and experimental framework inspired by experiential learning (Kolb, 1984), integrating phases of exploration, experimentation, and collective reflection. Open Labs were organized as hybrid environment for learning, experimentation, and knowledge exchange, activated simultaneously across the two regional contexts: Lombardy and Lazio. In line with the open innovation paradigm (Chesbrough, 2004; 2006), the Open Lab methodology enables the circulation of knowledge between internal (academic and scientific) and external (productive and social) domains, encouraging multi-actor co-creation and technology transfer (Faems et al., 2005). Open Labs were articulated into four main phases, developed iteratively and interconnected across the two regions:

- **Practical experience – Material testing workshops**: a hands-on experimentation phase involved students and researchers in the application of selected manufacturing and surface finishing techniques to the semi-finished materials. Predefined tools and fixtures (e.g., moulds, texture plates, CNC settings) were designed based on potential application domains. Each material was subject to sector-specific tests relating to its potential application within the 3Fs. This helped guide the definition of applicable product concepts. This phase served to increase the Technology Readiness Level (TRL) of the developed materials by evaluating their behavior under industrial processing conditions.

- **Reflective observation – Evaluation**: Material samples were evaluated through tailored assessment forms designed to capture both technical and sensory-perceptual properties. In this observation phase, students and researchers assessed how the materials' properties have been altered through experimental processing, considering changes in mechanical, structural, and tactile characteristics. This dual analysis helped define how the experimental work had influenced the overall material performance. Subsequently, the same material samples were evaluated by citizens, who provided a semantic and cultural interpretation of the materials using guided classification methods. This step explored how waste-derived materials are perceived by the broader public and how such perceptions can inform the identification of the most appropriate application sectors based on social and cultural acceptability. This phase aimed to integrate qualitative feedback into the development process, supporting human-centered innovation trajectories.
- **Abstract conceptualization – Co-design of application concepts**: Data collected from testing and evaluation were used in collaborative sessions involving all four helices of innovation. Participants analyzed the technical and perceptual performance of the materials to define coherent application scenarios and product concepts, anchored in the specificities of local production systems and guided by sustainability and feasibility considerations.
- **Active experimentation – Prototyping**: The final phase involved the physical realization of product prototypes based on the concepts developed. Prototypes were created by students, interns, and exhibitioners using both digital fabrication techniques (CNC, laser cutting) and low-tech processes, aiming to assess replicability, scalability, and industrial compatibility. Prototyping will focus on transforming 12 selected material samples into 24 innovative products, increasing their Technology Readiness Levels (TRL) and demonstrating their applicability in real use contexts.

3. Results and discussion

The above-described methodology led to a series of interlinked results that are described below following the different methodological steps.

3.1. Territorial recognition: From markers of excellence to waste identification

By-products from regional excellences were successfully identified within the 3Fs.

The selection filters used to identify marks of excellence are primarily intended to certify protected and controlled origin. In the food sector, marks can be applied directly to the final product, whereas in the fashion and furniture sectors, marks and consortia that guarantee production excellence have also been considered. This highlights that, in these industries, excellence lies not only in the finished product but also in the manufacturing techniques behind it. Table 1 presents the monitored markers, categorized by sector and accompanied by the relevant sources.

Regional excellences were investigated using the identified markers to catalogue typical Lombardy and Lazio products and processes. Each excellence was associated both with the relevant certifications for traceability and with the specific geographic areas, particularly provinces, where it is most prominent.

In the Fashion and Furniture sectors, excellences were further grouped into broader semantic categories to account for overlaps (e.g., “Leather processing and tanning” includes processing for bags, shoes, and belts). As a non-exhaustive yet illustrative example, Fig. 1 presents the mapping results of food-related territorial excellences in Lombardy.

In order to trace the scraps associated with the identified excellences, the production supply chain of each sector was first reconstructed. A systematic review of both gray and white literature enabled the identification of the production stages most relevant in terms of waste generation. This preliminary framework was subsequently cross-validated with the selected excellences to ensure consistency. Concurrently, companies operating within the identified areas of excellence were mapped and catalogued in a dedicated database. This dataset consolidates key information on companies in Lazio and Lombardy engaged in the domains of excellence across the three Fs.

3.2. Pilot waste reframing

The direct involvement of the mapped companies proved essential for collecting the information required in the subsequent stages of the research. Their participation not only confirmed the feasibility of the planned outputs but also provided additional insights that supported the definition of new investigative scenarios.

The identification of waste generated by companies of excellence, carried out through an indirect questionnaire, also served to assess their willingness to collaborate. Subsequently, direct interviews, conducted in full compliance with privacy and data protection regulations were used to evaluate the practical feasibility of such collaborations and to refine the list of promising scraps, ultimately restricting it to those documented in Tables 2–4. Workshops conducted among the RUs resulted in the development of initial application concepts and material morphologies, thereby establishing the foundation for subsequent experimental phases.

Table 1. Markers used as filter to identify excellence divided by the 3Fs

Food markers of excellence		***Fashion markers of excellence***		***Furniture markers of excellence***	
IGP	Protected Geographical Indication	**GOTS**	Global Organic Textile Standard	**UNI11674**	Requirements for determining the Italian origin of furniture
DOP	DOP - Protected Designation of Origin	**CFD**	Consorzio del Filo D'Oro	**FLA**	Federlegno – Assoarredo
DOC	Controlled Denomination of Origin	**IT01**	100% Made in Italy Certificate	**IT01**	100% Made in Italy Certificate
DOCG	Controlled and Guaranteed Designation of Origin	**CIT**	Consorzio Italian Texstyle	**CCV**	Valmalenco Quarrymen's Consortium
IGT	Typical Geographical Indication	**Federtessile**	National Chamber of Italian Fashion	**CVL**	Consorzio Vero Legno
STG	Traditional Specialty Guaranteed	**CNMI**	Confindustria Como	**CLAL**	Upper Lombardy Wood Consortium
De.Co.	Communal Denomination of Origin	**CC**	Artisan enterprises	**ARTIS**	Artisan enterprises
PAT	Traditional Food Products	**ARTIS**	Historic Mark of National Interest	**BMMA**	Ausoni Mountains Marble Basin
MIN	Historic Mark of National Interest	**MIN**	Certificate of Excellence	**CVTR**	Center for the Valorization of Roman Travertine
		CDE	Historic bottega Roma Capitale	**DGT**	Guidonia - Tivoli District (approval of Regional Law No. 168 of 2011.
		BSRC	Unioncamere - Historic Business Register	**RIS**	Unioncamere - Historic Business Register
		RIS	Liri Textile District	**DMA**	Monti Ausoni – Tiburtina marble district
		DTL	Federation of Textile and Apparel Industry Associations	**DVV**	Vulsini volcanic district
				DVC	Cimino Volcanic District
				CPV	Consortium for the Peperino of Vitorchiano
				DCC	Civita Castellana District

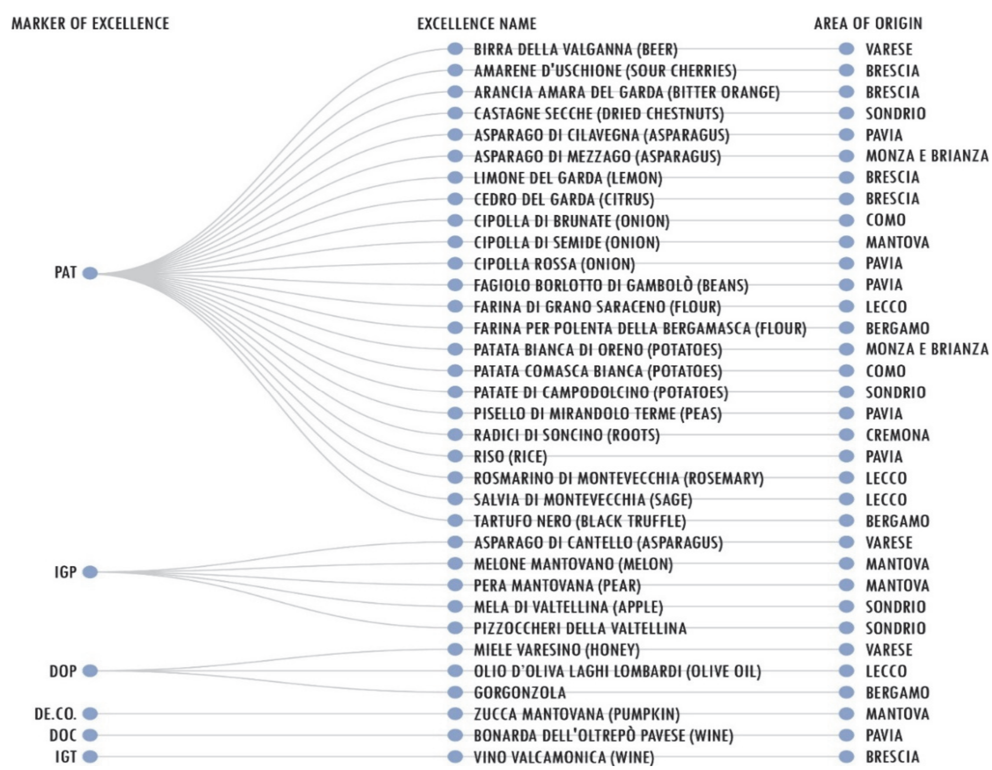

Fig. 1. Lombardy excellences, mapped in relation to specific markers and areas of origin

These workshops were structured as application-oriented brainstorming sessions, during which the RUs proposed potential areas of use associated with the mapped regional waste streams.

As a preliminary step, the research focused on identifying applications conceived as supports to be integrated within the scrap reference chain, thereby providing industrial utility for producers. For each morphology, the corresponding list of substances for its obtainment, predominantly of natural origin, in line with the project's objectives and the associated processing requirements were identified through the systematic review of scientific literature. The results of this phase are summarized in Table 5, which served as a reference point for the subsequent stage of material experimentation. These insights enabled the schematic definition of the experimental methods to be undertaken, allowing the physical and chemical characteristics of the different scraps to be effectively exploited. The approach described resulted in the development of 26 distinct semi-finished materials. A subsequent Open-Labs phase intends to explore additional application scenarios for these materials, ultimately leading to the final prototyping stage. Fig. 2 illustrates representative design-driven processes for material development.

3.3. Strategies for innovation: shared methodology and open labs

Over the course of the project, a progressively refined shared methodology emerged from the synthesis of two initial experimental approaches: the design-driven and the material-driven.

Table 2. List of identified waste associated with the corresponding excellence, region and supply chain stage in the food sector

Food			
Scrap	***Excellence***	***Region***	***Supply Step***
Asparagus turion	Asparago di Cantello/Asparago di Mezzago	Lombardy	Harvesting Processing
Olive pomace	Extra Virgin Olive Oil Laghi Lombardi	Lombardy	Processing
Olive pits	Extra Virgin Olive Oil Laghi Lombardi	Lombardy	Processing
Orange fibers and peels	Bitter orange del Garda	Lombardy	Processing
Orange pips	Bitter orange del Garda	Lombardy	Processing
Corn Husk	Polenta Bergamasca Flour	Lombardy	Harvesting Processing
Cornmeal	Polenta Bergamasca Flour	Lombardy	Processing
Rice straw	Rice	Lombardy	Harvesting
Wool	Abbacchio romano	Lazio	Processing
Shells, dust and hazelnut fragments	Nocciola Romana	Lazio	Processing
Artichoke stems and bracts	Carciofo Romanesco	Lazio	Processing
Kiwi peels, seeds and trimmings	Kiwi di Latina	Lazio	Processing
Fermentation residues	Limoncello, Elderberry Liqueur	Lazio	Processing
Grape pomace	Frascati Superiore, Cesanese del Piglio	Lazio	Processing

Table 3. List of identified waste associated with the corresponding excellence, region and supply chain stage in the fashion sector

Fashion			
Scrap	***Excellence***	***Region***	***Supply Step***
Leather dust	Leather processing and tanning	Lombardy	Weaving/knitting, Finishing and production
Rubber scraps	Leather processing and tanning	Lombardy	Finishing and production
Silk cascades	Silk processing	Lombardy	Spinning, Weaving/knitting, Finishing and production
Wool dust	Wool	Lazio	Weaving/knitting, finishing and production
Hemp fibers	Hemp	Lazio	Harvesting
Felt residue	Clothing	Lazio	Weaving/knitting, finishing and production
Technical clothing scraps	Technical clothing	Lazio	Weaving/knitting, finishing and production

Table 4. List of identified waste associated with the corresponding excellence, region and supply chain stage in the furniture sector

Furniture			
Scrap	***Excellence***	***Region***	***Supply step***
Pietra Ollare dust	Pietra Ollare Valmalenco	Lombardy	Processing, Manufacturing
Semi-cut Pietra Ollare scraps	Pietra Ollare Valmalenco	Lombardy	Material sourcing, Processing, Manufacturing

Shavings and sawdust	Furniture	Lombardy	Processing, Manufacturing
Textile cascades (Acrylic, Polyester, Polyamide)	Furniture	Lombardy	Processing, Manufacturing
Plastic scrap from packaging production	Furniture	Lombardy	Processing, Manufacturing
Natural stones' dust	Basalto/Tufo	Lazio	Processing, manufacturing
Marble dust	Travertino/Perlato	Lazio	Processing, manufacturing
Sawdust	Parquet e pavimenti	Lazio	Processing
Raw waste and sludge	Sanitary and furniture ceramics	Lazio	Material sourcing, processing
Basalt powder	Marbles and Stones	Lazio	Material sourcing, processing

Table 5. Identified morphologies (semi-finished outputs), together with the methods employed to realize these morphologies, wastes from 3Fs excellences to be used, and expected substances and processes to be adopted as derived from the scientific literature

CCMs semifinished outputs	***Laboratory method***	***Technical description***	***Example by-products***	***Additional materials and equipment***
Casted	Resin-based casting in textured molds	Incorporation of by-products into bio-based resins, followed by curing in silicone or metal molds.	Kiwi peels seeds and trimmings, Grape pomace, Olive pomace, Fermentation residues	Bio-resins, curing agents, silicone/metal molds
Paper	Mechanical and chemical pulp processing	Grinding and defibrillation of fibers in aqueous suspension, with enzymatic or chemical treatment for cohesion.	Leather dust, Grape pomace, Marble dust, Basalt powder, Rice straw, Asparagus turion, Artichoke stems and brats	Enzymes, pulp refiners, water
Gelled	Hydrogel formation with biopolymers	Dispersion of by-products in water, combined with gelling agents like alginate or pectin, followed by gelation under controlled conditions.	Leather dust, Orange fibers and peels, Kiwi peels seeds and trimmings	Alginate/pectin, calcium chloride (for cross-linking), reactors
Expanded flakes	Thermal or chemical foaming	Incorporation of expanding agents (e.g., carbonates and acids) into fiber-based mixtures, followed by thermal activation for cell structure expansion.	Orange fibers and peels, Kiwi peels seeds and trimmings	Carbonates, organic acids, controlled heating oven
Agglomerated panels	Thermocompression	Mixing fibrous materials with bio-based binders, followed by compression at specific pressures and temperatures to form rigid panels.	Textile waste, Wool, Felt residues, Hemp fibers	Thermocompressio n press, bio-binders (e.g., natural resins)
Extruded bio-composites	Extrusion or compression molding	Dispersing powdered by-products into a bio-based and biodegradable thermoplastic matrix, followed by extrusion or compression molding.	Leather dust, Olive pomace, Pietra Ollare dust, Artichoke stems and brats, Asparagus turion	Extrusion/injection machines, polymer matrix materials
Tiles/Slabs with ceramics	Powder with ceramic matrices	Grinding of by-products into fine powders, blending with clays or ceramic matrices and densification.	Marble dust, Pietra Ollare dust, Basalt powder	Ceramic binders
Coatings and pigments	Wet grinding and suspension stabilization	Fine grinding of by-products and suspension in a bio-binder matrix, with additives for viscosity control and dispersion stability.	Felt residues, Grape pomace	Bio-binders (e.g., casein, starch), stabilizers
Linoleum Sheets	Hot lamination and surface finishing	Mixing powdered by-products with linseed oil, natural resins and pigments, followed by lamination onto fibrous substrates like jute or hemp.	Shavings and sawdust, Hazelnut shells, Pietra Ollare dust	Hot laminator, linseed oil, natural resins and pigments, natural fabric
Yarn/Thread	Carding and Spinning	Pre-treatment of plant fibers via enzymatic or chemical softening, followed by carding and spinning into yarns.	Asparagus turion, Artichoke stems and brats	Enzymatic softeners, carder, spinning heads
Non-Woven Fabric (Felting)	Needle punching	Carding and layering of fibers, followed by consolidation via needle punching machines	Wool, Wool dust	Needle punching machine

Fig. 2. Examples of the application of REMODEL's research process applied to three cased (from left to right): arancia amara del Garda (orange), pietra ollare (soapstone), leather tanning

The resulting process is characterized by a double diamond structure, capable of integrating the convergent and divergent phases that define the two approaches. Specifically, it leverages the selective, goal-oriented dimension of the design-driven approach together with the exploratory nature of the material-driven one, which is oriented toward revealing the intrinsic potential of materials.

This methodological framework (Fig. 3) was further elaborated and applied in the design of the Open Labs, conceived as collaborative spaces for co-design and testing. Moreover, it enabled the activation of social creativity processes (Fischer, 2013), fostering the development of innovative solutions through the cross-pollination of disciplines, experiences, and perspectives.

Following a similar sequence of exploration and synthesis, new interviews with partner companies were conducted to gather additional contextual insights and to identify relevant application domains. On this basis, targeted experimentation was planned, focusing on shaping and surface-finishing techniques tailored to the specific requirements of each domain.

Finally, a dedicated phase of observation and qualitative evaluation of the experimental outcomes was carried out. This phase assessed both technical performance (e.g., physical and mechanical properties) and experiential perception through user involvement. The insights derived from this stage informed the final definition of product concepts, which represent a synthetic output of the process and provide the foundation for subsequent development and prototyping activities. The outputs of the Open Labs will converge in a series of final exhibitions serving a dual purpose: to disseminate the outcomes of the experimentation to a wider audience and to promote intersectoral knowledge transfer across the three 3F domains (Fashion, Food, Furniture). The exhibitions will showcase:

- 12 of the most representative CCM samples, tested and validated through the Open Labs;
- 24 product prototypes, developed through collaborative design and material experimentation;
- Visual and technical documentation of the processes, tools, and methods employed.

These exhibitions will act as catalysts for dialogue between research and industry while also raising public awareness of circular material innovation, in alignment with the Third Mission of universities. The Open Lab goes beyond the technological dimension, acting as a cultural and territorial tool for triggering local circular value chains and promoting forms of contextualized and inclusive innovation. It responds to the need for practical testing and co-development of solutions by engaging stakeholders from the quadruple helix: research, industry, policy makers, and citizens. Citizen participation, in addition to expanding the creative base, allows for testing the perception and acceptability of the materials, thereby helping to guide design choices. Companies contribute technical expertise and market knowledge, while policymakers play a role in strategic orientation and the definition of systemic scenarios, thus reinforcing an intersectoral dialogue that makes it innovative, replicable, and scalable. In this sense, the Open Lab serves as a catalyst for application opportunities, capable of transforming waste materials into enabling resources for new products and services, contributing to the increase of the TRL of the developed materials and the activation of new local value networks (Faems et al., 2005).

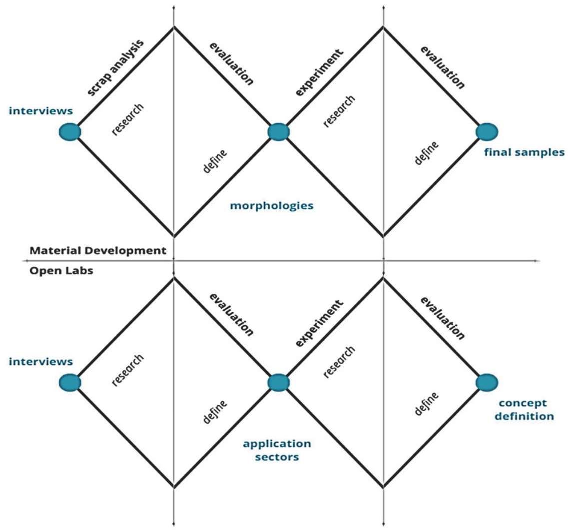

Fig. 3. Double diamond scheme of shared methodology developed for the material development phase, transposed for the Open Labs

The results obtained during the REMODEL project revealed several challenges that deserve attention and represent significant limitations for future developments.

The main challenges concern experimentation with Circular Composite Materials (CCMs). Starting from research and the collection of production waste, both small and large companies have shown strong interest in this experimentation, albeit with skepticism due to fears that academic research, without the intervention of an intermediary, such as a start-up, acting as a bridge between the academic and industrial worlds, could result in pure theory, without transfer and real application of the materials.

Consequently, the applied approach sought to develop processes that could also be replicated by small local producers, with the aim of facilitating the future transfer of methodologies to local production. The challenge was to integrate low-tech technologies for the development of CCMs into a production and cultural system deeply rooted in the territory, without compromising the authenticity and values that define 'Made in Italy'.

Another limitation that emerged concerns the management of the life cycle of the materials developed. While the development of CCMs has extended the useful life of materials, it has also raised doubts about their disposal once the product's life cycle has ended. This is linked to the need of measuring the actual impact of the solutions adopted, which must be addressed in order to avoid the general paradox that tends to assume that the transition to a circular model is globally beneficial, without considering the impact assessment. In fact, the environmental, social, and economic impact of the proposed solutions should be compared with the scenario of their disposal and production from different sources.

Finally, mapping scrap streams showed that the regulatory environment is a big hurdle to adopt circular solutions. The "End of Waste" regulation and the difficulty of treating valuable scraps as "by-products" rather than "waste" often don't recognize recovered materials as valid resources for an extended life cycle, creating problems in mapping and valuing scrap streams. For the upcoming phases of the project, the next challenge is the management of rights to the materials developed since their transfer could generate conflicts between academia and industry if not bound by specific agreements. Although the materials developed are tangible proof of how many opportunities for circularity are still being wasted today, it is essential to explore these aspects in depth to make the proposed solutions scalable and sustainable on a large scale. Future research should focus on how to measure the sustainability of the solutions developed, resolve issues related to intellectual property and technology transfer, and support the project with appropriate regulatory figures to promote the circularity of resources.

4. Conclusions

The REMODEL research project has enabled the testing of a blended methodological approach to the development of Circular Composite Materials using identified scraps materials as a starting point. Specifically, the project was built upon the necessity of revitalizing the Made in Italy companies and its excellent production chains by merging the academical research with ì industrial stakeholders' know-how while leveraging the solid principles of the circular economy.

In this regard, identifying application areas based on the key 3Fs reference framework was crucial for systematically planning the material experimentation phase. The results of this research have been extensive, both in terms of material quantity and potential applications.

The next phase of the REMODEL project is focused on prototyping, a key moment within the Open Labs aimed at transforming experimental outcomes into tangible and verifiable objects. This hands-on validation will make the entire circular innovation cycle visible, demonstrating the project's potential impact across the different supply chain sectors.

Local companies will be actively involved in co-defining product concepts and will have the opportunity to evaluate outcomes through the final exhibitions. The project shows how companies can reimagine high-quality Made in Italy by adopting new strategies for by-products valorization through design and material innovation. This approach could generate economic and cultural value within and for local territories, strengthening identity and fostering a new, more sustainable production vision.

In addition to the findings presented, two further important limitations should be highlighted. Firstly, the research covered a limited geographical area (Lombardy and Lazio) and focused on specific 3F sectors. Secondly, the technical validation of CCMs is currently limited to a prototype phase. For this reason, industrial scalability, performance and durability of the materials developed, as well as their end-of-life remain open topics. Looking ahead, efforts will be made to extend the mapping of waste streams to other geographical areas and production sectors. Finally, the expansion and adoption of increasingly diverse co-design practices, such as workshops or idea competitions in academia, will promote a broader spectrum of action towards circular innovation.

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