Cumulus Conference Proceedings

Nantes, France 2025

ethical leadership
a new frontier for design

L'ÉCOLE DE DESIGN Nantes Atlantique

Cumulus Association

Ethical Leadership: A New Frontier for Design
Hosted by L'École de design Nantes Atlantique
Nantes, France, on June 3-7, 2025
Conference website : https://cumulusnantes2025.design

Published by Cumulus
Cumulus the Global Association of Art and Design Education and Re-search.
C/o Aalto University, PO BOX 11000, FI-00076 Aalto, Finland
https://cumulusassociation.org/

ISBN 978-952-7549-07-0 (PDF)

Cumulus Conference Proceedings Series, No. 14

ISSN 2490-046X

Editor-in-Chief:
Cumulus President Lorenzo Imbesi

Editors :
Frédéric Degouzon (L'École de design Nantes Atlantique)
Jade Gagnepain (L'École de design Nantes Atlantique)

Publications in the Series:

01/17 Kolding, REDO
02/17 Bengaluru, Letters to the Future
03/18 Paris, To get there: designing together
04/18 Wuxi, Diffused Transition & Design Opportunities
05/19 Rovaniemi, Around the Campfire – Resilience and Intelligence
06/19 Bogotá, The Design After
07/21 Rome, Design Culture(s) Volume #1, Volume #2
08/23 Guayaquil, Arts imagining communities to come
09/23 Detroit, Design for Adaptation
10/23 Antwerp, Connectivity and Creativity in times of Conflict
11/24 Beijing, Narratives of Love
12/24 Budapest, P/References of Design
13/25 Monterrey, Design Across Borders – United in Creativity
14/25 Nantes, Ethical Leadership: A New Frontier for Design

Ethical Leadership: A New Frontier for Design
Cumulus Conference Proceedings Nantes 2025
Conference Chair: Frédéric Degouzon (L'École de design Nantes Atlantique)
Conference Project Manager: Jade Gagnepain
Design: Esther Medeiros
Visual Identity : Eliott Gouyette, Julie Durand, Louna Mignonneau, Matthias Rischewski

Layout:

ethical leadership
a new frontier for design
JUNE 3–7, 2025
Nantes, France
Cumulus Association
L'ÉCOLE DE DESIGN Nantes Atlantique

Design-led waste management: enhancing stakeholders information exchange for circular productions

Viktor Malakuczi, Luca D'Elia, Carmen Rotondi, Paola Altamura, Mariia Ershova, Gabriele Rossini, Alessandro Aiuti, Sabrina Lucibello, Serena Baiani, Emanuele Panizzi, Lorenzo Imbesi

Sapienza University of Rome
*viktor.malakuczi@uniroma1.it

ABSTRACT | To enable sustainable future production systems, waste management is a crucial issue, and designers may assume the role of leadership by negotiating proper material use among various stakeholders that allows resources to be reintegrated into life cycles and establishing new production hierarchies that prioritize waste prevention and capitalize on market opportunities. The presented research investigates ways of stimulating circular material use in the furniture industry, where a transformation has already started, in part due to economic interests and shifting consumer sensibility, but mostly due to a regulatory push towards more sustainable solutions, especially in case of public procurements. While designers have long been experimenting with recycled materials and their distinct visual identity, it is still challenging for them to find locally available circular material options and comprehend their real environmental impact. Due to this difficulty, sustainable and circular design typically requires specialised experts, as well as more time and resources. To mitigate this issue and allow designers to be not only creative leaders, but also agents of sustainable material choices since the initial product conception, this project examines the possibilities of using advanced digital tools for facilitating the design process and, in particular, information flows between three key stakeholders: designers, furniture manufacturers, and waste managers (secondary raw materials). Interviews with these stakeholder categories led to identifying insights organised in three main problematic areas about circular materials: limited awareness and mistaken perceptions; lack of trust in the environmental impact data; difficulty of choice and supply chain setup. Subsequently, based on the identified requirements, a twofold system of digital tools was designed, comprising an online platform for collecting and exploring circular materials, and a CAD software plugin for channelling circular materials into the design process, allowing designers to quickly confront estimates of environmental impact of different material combinations. AI-driven features have been designed into various workflows, from material uploading to search, recommendations and comparisons in natural language. The developed knowledge and experiments will contribute to a more effective digital toolbox for designers, allowing them to become leaders of circular transformation and proactive professionals who not only do the right design choices, but also help to establish local and circular supply chains.

KEYWORDS | SUPPLY CHAIN, LCA, MATERIALS, DESIGN TOOLS, ARTIFICIAL INTELLIGENCE

1. Introduction

In today's context, the transition toward a sustainable future is imperative and involves all sectors, with design playing a crucial role in this evolution. Designers are no longer just creators of form and function but leaders capable of driving change through design practices promoting sustainability, ethics, and innovation. One of the most urgent aspects, particularly, concerns waste management and the integration of circular production practices, which has become increasingly central in research agendas and industrial policies. The European Commission (2024) highlights how limited access to product sustainability information remains a significant barrier to design-based entrepreneurial initiatives, preventing a genuine transition to circular business models. In this scenario, designers can assume a leadership role by negotiating material use among the various stakeholders involved, creating co-creation networks that facilitate the reintegration of resources into production cycles. However, to effectively address this challenge, designers must have adequate tools and a solid knowledge base to make informed decisions.

This paper presents ongoing research that explores the use of digital tools. Appropriate tools can facilitate the adoption of circular solutions in complex production environments by supporting a more transparent and collaborative decision-making process (Eriksson et al., 2022). The goal is to improve product circularity by making crucial information accessible to various stakeholders and encouraging interaction among all parties involved in design and production. The research project focuses mainly on the Made in Italy furniture sector, which is known for its excellence but is still characterized by limited recycling, reuse, and certification practices (Silvius et al., 2021; Barbitano et al., 2019; Savelli et al., 2019). By using digital platforms for material and data exchange among designers, manufacturers, and other stakeholders, the project aims to develop an organizational model that can be replicated in other sectors, promoting circularity on a global scale. This approach not only helps reduce waste but also creates new market opportunities, focusing on enhancing economic and environmental sustainability.

In this article, the evolving role of the designer will be highlighted, as they not only increasingly assume leadership roles but also take responsibility for their ability to create networks that make strategic decisions with a positive impact on society and the environment. These skills can also be applied in entrepreneurial contexts to develop ethical and sustainable businesses that respond to global challenges. However, this process requires a shared understanding of co-creation dynamics and the ability to navigate different creative cultures while simultaneously changing organizational models and adopting new digital tools (Cusumano et al., 2019). In this context, ethical leadership through design-driven entrepreneurship becomes central. As leaders, designers should face the dilemma of maintaining their creative essence while taking on new responsibilities. They should be capable of addressing the challenges of adopting circular business models, sustainable practices, and public-private collaborations. This paper will demonstrate how the evolution of design as a tool for building a more sustainable future also involves promoting a cultural shift that encourages dialogue, transparency, and responsibility. Moreover, in order to support these new paradigms, the research develops digital tools to be introduced between the various stakeholders.

2. Circularity in the Italian furniture value chain

The Italian furniture industry, valued at approximately EUR 17.5 billion annually, is a significant part of the EU market, ranking after Germany, the UK, and Poland (EEB, 2017). It is a cornerstone of the "Made in Italy" brand, recognized for its high-quality design and strong export contributions. The sector, largely composed of micro-sized enterprises concentrated in the North, faces growing challenges, including rising energy and raw material costs. To address these challenges, the use of secondary raw materials has gained prominence, positioning Italy as a European leader in circular economy (CE) practices within the wood-furniture sector (Symbola Foundation & Federlegno Arredo, 2016). However, the broader Italian furniture sector lacks full circular economy implementation, with companies mainly focused on activities directly related to business efficiency and immediate economic benefits such reducing raw materials or energy consumption (40%), developing low-resource production processes (36%) and environmental criteria for supplier selection (33%) (Fondazione Symbola & ENEL, 2021).

1.1 Procurements criteria and best practices

In this context, Mandatory Green Public Procurement (GPP) has emerged as a crucial driver for advancing circularity and sustainability within the sector, leveraging public sector purchasing power, which accounts for 14% of EU GDP (EU Commission, 2024). Italy's Minimum Environmental Criteria (MEC), mandatory since 2016, require the use of recycled or renewable materials, modular design, and non-destructive disassembly to facilitate reuse and recycling (EEB, 2017). GPP MEC for urban and indoor furniture, established by the Ministry of the Environment in 2015 and 2017 and updated by Ministerial Decrees (07/02/2023; 23/06/2022), provides a regulatory framework aimed at increasing the use of circular materials. The application of MEC has reached an average of 62% (Legambiente, 2024), contributing to the rapid growth of Environmental Product Declarations (EPDs), which rose from 5 in 2016 to 509 in 2024, demonstrating a clear shift towards transparency and sustainability. MEC criteria specify minimum recycled content requirements - ranging from 100% for wood to 5% for concrete - and address factors such as hazardous substances, energy efficiency, and recyclability. Compliance is verified through certifications such as EPDs based on life cycle assessment (LCA) and mass balance methods, ensuring traceability and credibility.

Also, environmental certifications play a crucial role in promoting circular materials and products. In Italy, certifications such as ReMade in Italy and Plastica Seconda Vita focus on verifying recycled and by-product content, while holistic schemes like Cradle to Cradle (C2C) consider broader circularity aspects, including material health. The research analyzed certification databases, including EU Ecolabel, C2C, ReMade in Italy, Plastica Seconda Vita, and EPDItaly, with a focus on the ReMade in Italy catalogue, which contains the highest number of nationally certified furniture products (ReMade, 2024).

Established in 2013, ReMade in Italy certifies recycled material content in materials, semi-finished, and finished products across various sectors. It requires traceability plans, supplier monitoring, and material classification, ensuring compliance with Green Public Procurement Minimum Environmental Criteria (GPP MEC). Certified products benefit from tax incentives and demonstrate environmental advantages such as reduced energy consumption and lower CO2 emissions. The ReMade in Italy catalogue for indoor furniture has grown to 184 certified products, with school furniture (42%) and seating (34%) as the most represented categories. However, certification adoption remains limited to a few large companies, with 70% of certified products belonging to just five firms. Only 15% of products achieve the highest A+ rating (more than 90% recycled content), such as the Sfera waste sorting container (97% post-consumer ABS). About 50% of certified indoor furniture contains over 60% recycled content, particularly in school tables and seats made of wood, metal, and plastic (MobilFerro). Plastics and wood dominate the certified materials, aligning with MEC criteria for indoor furniture, while coatings and other recyclable materials, such as paper, aluminium, and glass, are underrepresented Despite these advancements, full circularity adoption remains a challenge, as companies still focus primarily on cost efficiency and their numerous challenges in qualifying waste for production processes. Strengthening stakeholder engagement and aligning business strategies with evolving sustainable requirements – as GPP – will be key to further advancing circular practices in the Italian furniture industry (Donatello et al, 2017).

In this sense, the role of the designer can be important in catalysing new conceptual and operational frameworks, acting as an intermediary between the regulatory complexity and the relational complexity of the production and industrial fabric.

3.1 A framework for waste valorisation in the Italian furniture value chain

The research sought to outline a methodological framework, modelling the entire life and design cycle of a furniture product, including the flows of materials and waste, components and materials, and their secondary cycles triggered by the 9 R's (Refuse, Reduce (by design), Reuse, Repair, Refurbish, Remanufacture, Repurpose and Recycle)[1] (Reike, 2018) and introducing at the same time all the different information flows, necessary to make them possible. The close correlation between the material flow related to the product lifecycle and the flow of information that manages and accompanies the different stages that characterize it (figure 1), again emphasizing how the transition to a more circular economy is intertwined with its digital transformation (CENFIM, 2021). Both material and information flow together with the key documents allowing awareness of environmental and circularity profiles of materials and products.

Fitting into this general framework of circular design and production, the present research is introducing two interconnected digital tools (green in figure 1): an Online Platform for circular material (data) exchange and a CAD Plug-in to channel such material data directly into the design process of furniture, thus returning to the designer some of the key information related to the environmental impact of locally available circular materials. Therefore, the project focuses on the phases of material production and component production, where allowing designers and manufacturers to make more informed material choices could have a major overall impact.

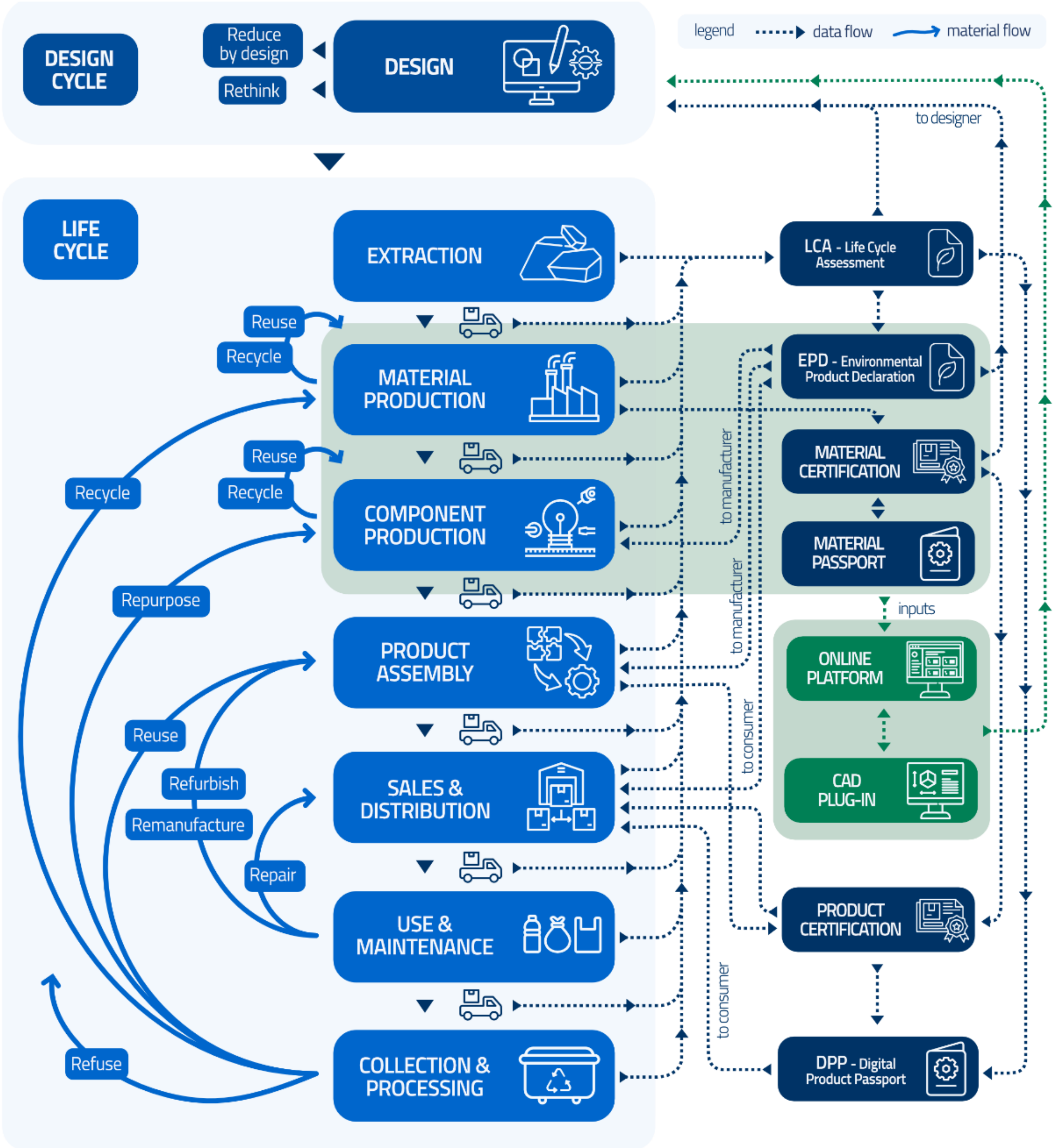

Figure 1. Flow diagram summarizing the methodological framework for circular design and production of furniture, based on enhanced data and information flows and on the implementation of the 9 Rs.

The diagram shows all the steps that contribute to the development of circular material- from the recovery and classification of waste/subproduct to the production and certification of semi-finished and finished products. This complex process requires characterization of waste materials, tracing their path, environmental study and technical/legal framing. For each identified phase, there are many actors involved (the supply chain, the manufacturing company, the reclaimers, the transporters, the laboratories for material testing, the intermediaries for the regulatory and certification part, LCA analysts, etc.), whose needs and any support tools already used must be coordinated with each other, reconciling requirements and resolving any criticalities: in this sense, the designer assumes the role of leader of the entire process, responsible for

effectively coordinating the different becomes professional figures with specific skills.
In this model, designers work by adopting a life cycle-oriented eco-design methodology, which implies their involvement not only strictly in the design cycle but also from a broader perspective in the production process and in consideration of all phases of the life cycle, using smart tools for sourcing secondary materials, for the valorisation of rejected components and parts, for the evaluation of the environmental profile of the designed product, etc. In this scenario, customers, whether businesses or consumers, need more detailed information about products and their sustainability characteristics, including life cycle environmental indicators (LCA Studies, EPDs, Digital Product Passports, and Material Passports). Data collection for each process therefore requires an appropriate digital infrastructure and data collection procedures that ensure transparency, traceability, and security.

Within this framework, rethinking and reducing by design approaches allow for the exploitation and optimization of in-house by-products and reused and recycled waste, end-of-life products reused after repair/remanufacturing/refurbishment actions, post-consumer waste reprocessed by recycling companies, and products that are rejected, i.e., not purchased by consumers. More conscious and informed decisions on behalf of the designers would make it possible to ensure greater material resource efficiency, right from the conception of the product itself, influencing the various stages of the production process and thus the entire product life cycle.

4. Key stakeholders for enhancing circular material use

To encourage conscious furniture design from the outset by giving designers a leadership role, this research is developing a multi-stakeholder system through advanced digital tools, as already anticipated in the previous section. Specifically, the aim is to promote the circular use of materials in the Italian furniture industry by facilitating connections between designers and key stakeholders: waste managers, who provide secondary raw materials or by-products, and furniture manufacturers, who can directly utilize circular materials. The development of these digital tools began with stakeholder mapping, followed by interviews to identify their problems and needs, ensuring their interest in the system participation.

4.1 Stakeholder mapping

The qualitative research phase involves adapting methods to ensure timely and relevant data collection across various disciplinary settings (Vindrola-Padros & Johnson, 2020). This phase includes semi-structured interviews to delve deeper into the information retrieved during the desk research phase (Safdar et al., 2021). Through a qualitative analysis of semi-structured interviews with key stakeholders, valuable insights and perspectives from individuals involved in the system have been retrieved, which has been ultimately clustered and analysed according to the project-grounded methodological approach (Corbin & Strauss, 2008). This analysis provides initial insights into the common knowledge base producers and manufacturers have about waste management within the Made in Italy production chain.
To map the stakeholders, the research analysed regulations and identified waste-generating processes using ATECO codes, which classify economic activities in Italy and define the eligibility for tax benefits and sustainability compliance. The study identified 56 ATECO codes linked to 487 industries relevant to waste management. Specialized consortia play a key role in intermediate recycling activities, aiding designers in creating

sustainable products.
For waste managers, the focus was on ATECO 38.32 ("Collection and sorting of materials"), identifying 113 companies, with 40 selected based on financial stability. Additionally, 45 manufacturing-related codes were analysed, particularly in fashion and furniture, identifying 374 companies, including 141 in Lazio for strategic collaboration.
For designers, the study prioritized professionals integrated into production chains. Eight ATECO codes covering consultancy and research were also identified for potential external collaboration.

4.2 Participant Organizations: roles and positions

After stakeholder mapping, the research conducted interviews with various types of stakeholders involved in the system, including two designers and six stakeholders:

- Designer 1 is an independent designer specializing in Product Design, Packaging, and Strategic Design.
- Designer 2 is an independent designer focusing on Product Design, with a particular emphasis on bathroom furniture design.
- Stakeholder 1 is a producer of indoor rubber floor coverings, which are mainly used in public buildings and private facilities.
- Stakeholder 2 is an intermediary in the environmental services sector that combines operational services with technical and scientific advice to reduce the environmental impact of its clients.
- Stakeholder 3 is a consulting and research company, specializing in the sustainability of materials and products, and in defining metrics for measuring the circular economy.
- Stakeholder 4 is a trade association that represents and defends the interests of inert waste recyclers to create the necessary conditions for the development and growth of the recycled aggregate market.
- Stakeholder 5 is an association reserved for operators in the rubber and elastomer recovery sector, fostering further aggregation potential in the area.
- Stakeholder 6 is a manufacturer engaged in the production of modular shop fittings, accessories, display windows, furnishing elements, and mannequins.

Initially, the roles were defined as designers, waste managers, and furniture manufacturers. However, the interviews revealed that these roles often overlap, making strict classifications challenging. For example, stakeholder 8, identified as manufacturers of furniture, also acts as a waste producer, managing production residues and seeking ways to valorise them. Similarly, some stakeholders take on hybrid roles, such as intermediaries (stakeholder 2 and 3) who provide consulting and technical services, or associations (stakeholder 4 and 5) that represent collective interests while also participating in the waste-material-product chain. This underscores the fluidity of roles within the circular economy, where organizations may shift roles throughout their operations, reflecting the system's interconnected nature.

5. Insights from the ecosystem

Among the various information that emerged during the interviews, problems and needs define a general pattern of topics that have been clustered according to three thematic groups: 1) awareness, communication, and market adoption, 2) quality, availability, and certification of information, and 3) product development, evaluation, and production processes.

5.1 Awareness, Communication, and Market Adoption

A key issue that emerged is the lack of awareness and market acceptance of circular materials, by which stakeholders 4 and 5 emphasized the need for specific marketing channels along with a more strategic engagement of the public to improve product perception, as recycled materials are often undervalued. According to this, stakeholder 1 highlighted the relevance of storytelling in promoting circular economy practices and stakeholder 8 pointed out that materials derived from materials such as MDF powder are often perceived as waste rather than valuable resources, limiting commercialization. Designer 2 emphasized the need for direct dialogue with technical offices that could enable better alignment between design and production constraints, even though the perception that companies are reluctant to adopt sustainable materials due to high costs, limited availability, lack of certification, and aesthetic concerns. In this case, it emerged that many businesses hesitate due to process adaptation challenges and fears of inefficiencies.
As highlighted by the interviewed designers and other stakeholders, the design of the final product plays a key role in creating engaging communication strategies. It serves as a strategic tool to help companies integrate sustainable materials by designing narratives on a multi-stakeholder interface that facilitates the exchange of intelligible and reliable material-related information among manufacturers, suppliers, and users.

5.2 Quality, Availability, and Certification of Information

Another major challenge is the lack of verified and accessible information about traceability, which affects circularity and sustainability. Indeed, stakeholders 2 and 3 emphasized the need for Digital Product Passports to improve transparency, pointing out that manufacturers often codify material information to protect supplier data, creating trust issues in material selection. Stakeholder 6 reported complex and time-consuming certification processes, delaying market entry for sustainable products. Additionally, ESG data collection is still manual and inefficient, lacking structured methodologies for LCA (Life Cycle Assessment) and carbon footprint calculations, highlighting that many companies claim to have no waste, making it difficult to assess material availability and sustainability impact.
To address these gaps, as highlighted by the designers involved, a comparative approach based on sustainability metrics could enhance the adoption of sustainable materials among manufacturers. Cross-referenced data could be integrated throughout the design and production stages, ensuring accessibility and usability for designers. By incorporating objective sustainability assessments, this approach would support informed decision-making and foster more responsible material choices in design processes.

5.3 Product Development, Evaluation, and Production Processes

Stakeholders 1 and 2 identified that managing multiple material attributes (e.g., cost, performance, quantity, aesthetics, environmental impact, logistics) is challenging due to the difficulty of evaluating and visualizing material properties, particularly in clear and intelligible data formats. In this regard, stakeholder 3 suggested that automated material recommendations and improved demand-supply matching could be beneficial. Additionally, stakeholder 6 highlighted challenges in scaling up sustainable innovations, citing high production costs and the need for innovation in the manufacturing chain. This includes integrating digital fabrication processes and adopting more adaptive and modular panels to ensure reliable traceability and regulatory compliance. These

challenges require the integration of a robust tracking system.
In product design and development, both designers emphasized the need for tools that support the assessment of material sustainability, comparison of options, and guidance for assembly with reuse in mind, while also estimating product longevity. They highlighted that digital tool, when enhanced by well-trained AI evaluation systems, could enable designers to make informed choices, ensuring materials align with sustainability goals while optimizing performance, longevity, and recyclability. Additionally, they stressed the importance of establishing direct communication channels between designers and manufacturers to streamline file preparation, prevent misinterpretations, and improve production efficiency.
Based on the results of the interviews, it is possible to outline a hypothetical path of development. Shifting from a linear model to a circular one requires shared responsibility in recycling and a design approach that prioritizes circularity from the outset. This means integrating sustainability data, optimizing supply chains, and ensuring cost-effectiveness to maintain competitiveness in a more sustainable Made in Italy. Key actions include implementing Digital Product Passports for traceability, strengthening legislative support, and launching marketing campaigns to shift perceptions of recycled materials. Additionally, AI-driven tools for material selection, durability assessment, and assembly guidance can enhance efficiency, while fostering direct collaboration between designers and the diverse stakeholders will streamline sustainable production.

6. Guidelines for better tools

The digital tools proposed by the current research will need to respond to the issues raised by the stakeholders previously described, therefore the interview findings above were used as an input for identifying the system requirements and principles to follow. These will be discussed according to the same threefold division.

(1) The first group of issues revolves around the awareness of available circular materials both for designers, manufacturers and consumers themselves, who perceive quality as inferior. While communication to consumers is out of scope for this project, limited sustainability information may be addressed also with innovative digital tools. Waste exchange platforms are not a new concept, but there is no tool focusing on the territorial peculiarities of Made in Italy furniture. Participants highlighted the need to support various supply chains, with adequate differentiation of roles and functionalities.
(2) Another recurring issue is the lack of trustworthy information and the difficulty of finding the relevant pieces of information, especially in fields that are not (yet) heavily regulated. While software tools for Digital Product Passports are being introduced due to EU legislation, there is a twofold issue: material sources are sensible information for companies, while there is a general mistrust in how strictly companies follow sustainability standards. Better digital tools might help avoid unintentional omission of relevant details, and may proactively invite stakeholders to verify relevant indicators, and perhaps enhance practices.
(3) The final group of issues is about the product development and evaluation process. At the moment, designing with circular materials and setting up a trustworthy supply chain requires specialized expertise, thus making circular product development much slower and more expensive. Digital tools may help to bridge this information and expertise gap by providing sustainability knowledge and up-to-date supply information at the adequate points of the product design and engineering process, also relying on AI processing capabilities that became mainstream recently. Considering various in-house software solutions, a crucial aspect is interoperability: new digital tools should aim at openness and modularity, either through proper open-sourcing, or through public APIs (Application Programming Interfaces) so that any new solution may be quickly integrated

into existing tool chains.

Among these features, the key aspects that enhance designers' leadership capabilities are the expansion of information access and stakeholder collaboration through a seamless workflow. The tool should empower designers with data-driven decision-making by providing access to a national sustainable materials database and an AI assistant for comparative analysis. Simultaneously, it should facilitate direct interaction with other stakeholders, fostering collaboration and serving as a foundation for informed dialogue. To ensure a smooth and efficient workflow, the digital tool will be integrated into CAD software, allowing designers to incorporate sustainable materials seamlessly into their design process.

7. Enhanced workflows through new tools

Based on the previously discussed results of the analytical steps, both regarding current practices of evaluating material sustainability and regarding the mapping of stakeholder needs, the research has outlined practical examples of how the three categories of stakeholders would benefit from the multi-stakeholder system, describing the user journey for each of them. The hypothesized multi-stakeholder system consists of coherent workflows for three main users: designers, waste managers, and furniture manufacturers. Following previously described emerging opportunities, the digital tool integrates conventional CAD software with AI features and a recommendation engine to assist designers and manufacturers in material selection.

7.1 User Journey

On one side, the digital tool incorporates bottom-up processes by collecting data from waste managers through a web interface. Waste managers provide detailed information about their company and the materials they want to sell, including production details, material categories, aesthetic characteristics, and life-cycle parameters. Subsequently, designers and manufacturers can browse the material catalogue via the web interface, using filters to explore options and conduct comparative analyses of materials with AI-driven suggestions. The designer and manufacturer workflow concludes with material selection based on environmental impact and other parameters, leading to a purchase from the waste manager.

At the same time, the digital tool integrates with conventional CAD software, such as Rhinoceros, through plug-in. When the designer has finalized the geometric shape of the furniture, they can use the plug-in for material selection. The designer's workflow begins with the creation of material and shape groups by assigning parts of the geometry. The designer can then set multiple materials from the web interface to these groups. Finally, the designer can assess various material configurations through comparative environmental impact analyses, enhanced by AI suggestions, and apply the selected textures to the geometry for aesthetic evaluation. The system also incorporates top-down processes, involving the evaluation of various international and national environmental indicators. These indicators are narrowed down to two or three for integration as input queries, filters, and the basis for AI recommendations.

7.2 Interfaces

The research developed a set of mockups illustrating the user journeys, which involved developing initial high-fidelity user interfaces of a website and a plug-in for CAD software. The website supports two main workflows: selling, for waste managers, and buying, for designers and manufacturers of furniture. The plug-in is designed especially for designers and requires basic CAD software skills.

The mockups were developed, to test with stakeholders, then refined, and finally developed into functional prototypes. Considering that this research is part of a larger project, the design system for Italian public digital services was chosen to ensure alignment and integration[2]. The main workflows were illustrated through a selection of mockups, in the following order: setting up material variants within the CAD software through a plugin (figure 3 and 4) and browsing and comparing materials through the web platform (figure 2).
Thus, the digital tool enhances designers' leadership by integrating the national sustainable material database, AI-assist, stakeholder network, and seamless CAD integration, enabling informed and sustainable decision-making in the circular economy.

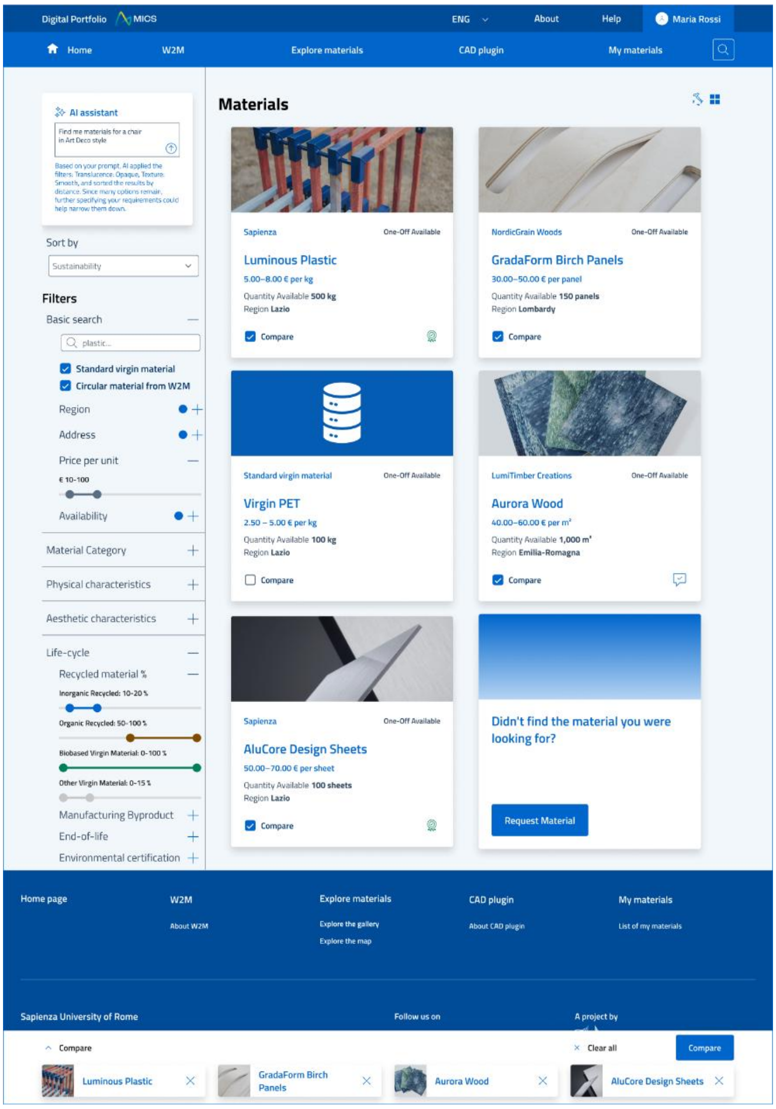

Figure 2. Catalogue of materials with filters for designers and manufacturers of furniture.

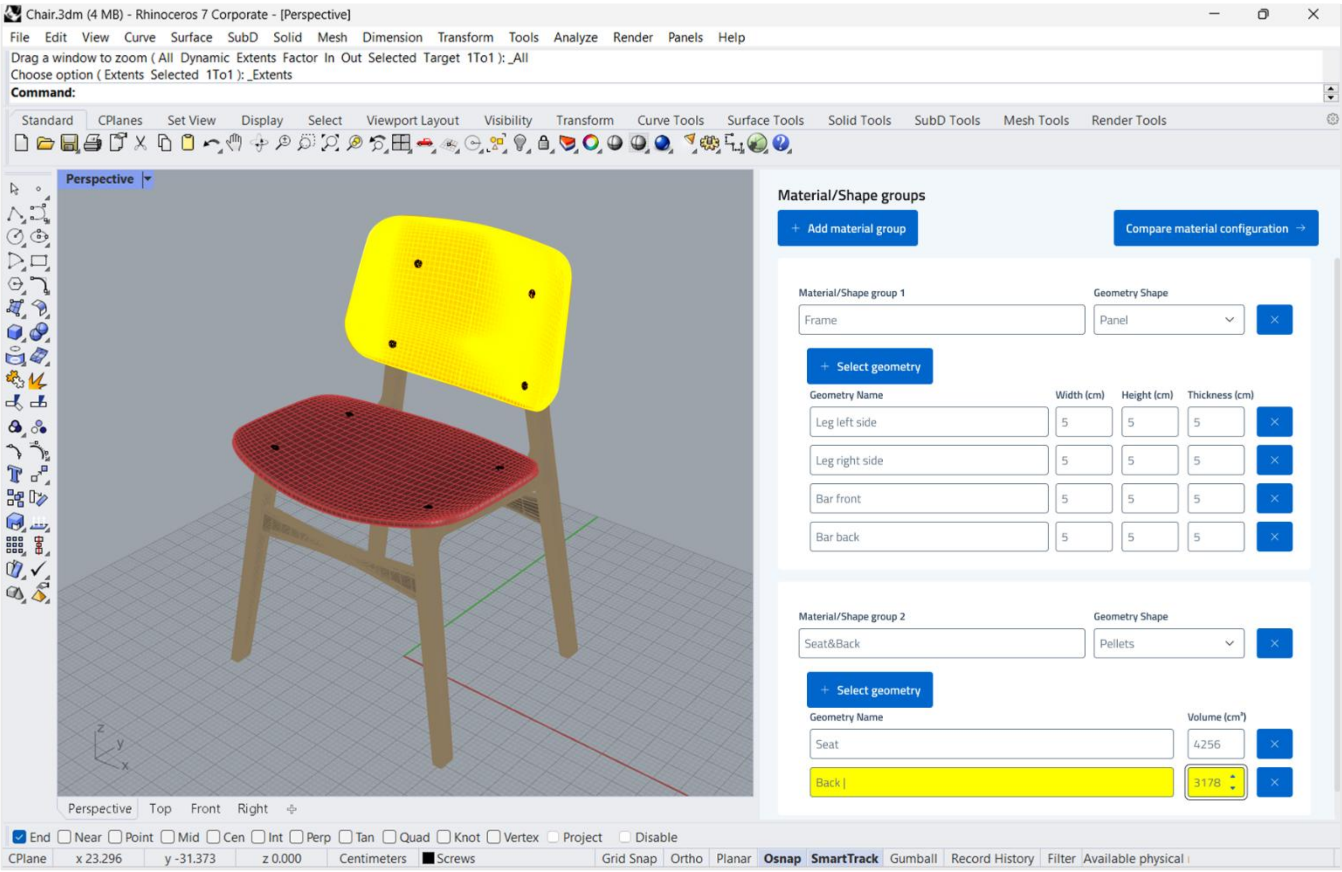

Figure 3. Interface for designers, integrated into the CAD software Rhinoceros 3D, for creating material/shape groups (groups of components that will be manufactured from the same material, with the same starting form, e.g. panels to be cut).

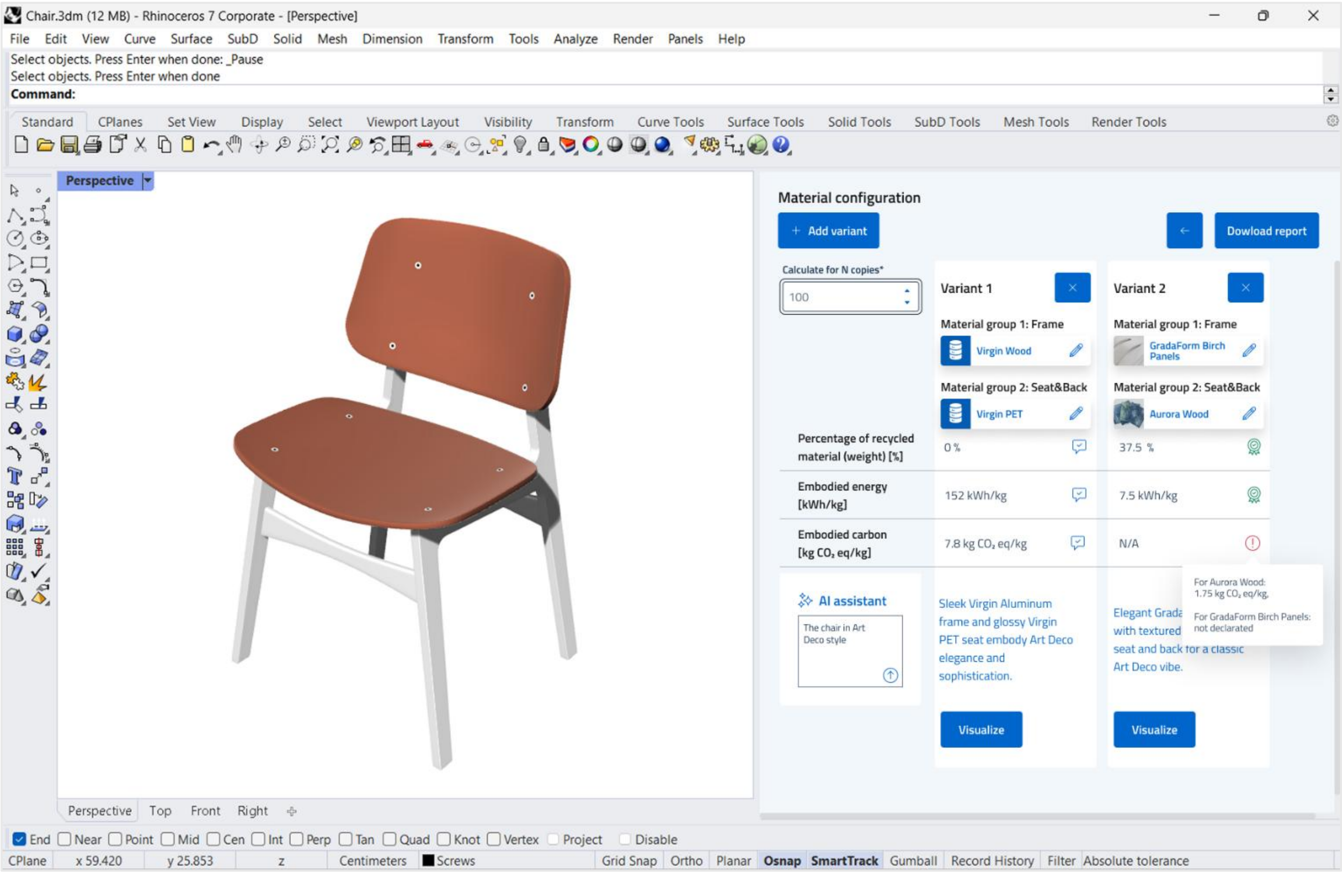

Figure 4. Interface for material variant comparison, once all materials have been associated with the material/shape group, with AI suggestions and a set of key sustainability metrics for comparison.

8. Advanced AI capabilities for the multi-stakeholder system

The proposed project is an innovative web-based platform designed to facilitate circular economic practices by connecting waste managers, designers, and manufacturers. A key technological advancement is the integration of AI-driven capabilities to efficiently manage, retrieve, and correlate unstructured data, optimizing material documentation and discovery.

Most materials-related information exists in unstructured formats, making it difficult to systematically retrieve and correlate relevant data. Traditional data extraction methods have relied on manual curation or rule-based systems, which are not scalable and require domain expertise. Large Language Models (LLMs) present a scalable alternative, enabling structured data extraction from diverse and unstructured sources (Schilling-Wilhelmi et al., 2024), significantly accelerating the discovery and reuse of recycled materials.

Waste managers use the platform to upload detailed information about recycled materials, including textual descriptions, images, and technical files compatible with modelling software. AI-driven structuring minimizes manual effort, ensuring consistency and accessibility. Designers and manufacturers, in turn, leverage advanced search tools powered by LLMs and retrieval-augmented generation techniques to discover suitable materials for their projects (Jiang et al., 2023). By iteratively refining query understanding through AI reasoning, the platform dynamically enhances search results, improving precision and relevance (Jiang et al., 2023).

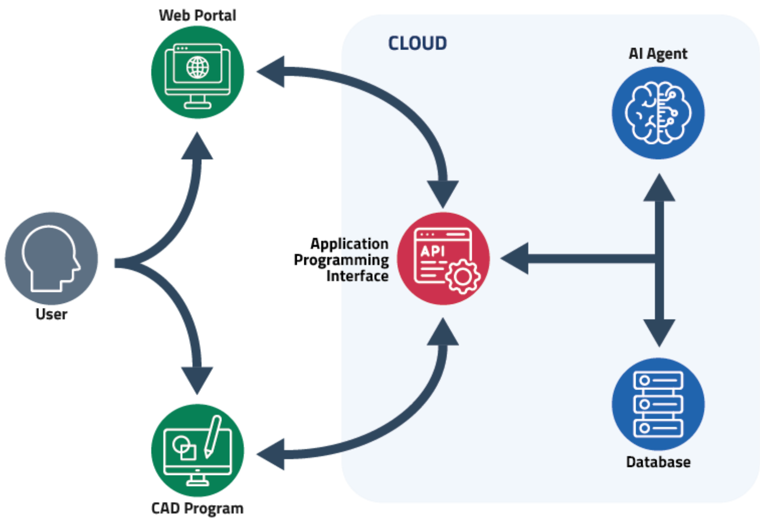

Figure 5. System Architecture Overview: The platform enables users to interact with a web portal or CAD program, which communicates through an API to access cloud-based AI processing and a structured database. The AI agent helps process unstructured data, while the database stores and retrieves material information efficiently, facilitating seamless integration between stakeholders.

At the core of the system lies the transformation of unstructured data into structured JSON outputs, making them easily searchable and integrable within a high-performance, cloud-based database. Research on AI-enhanced data retrieval has demonstrated that users modify their querying strategies over time, necessitating adaptive AI systems capable of learning and evolving with user behaviour (McCamish et al., 2018). This approach ensures that designers and manufacturers can iteratively improve their material discovery process, shifting from static retrieval models to more intuitive and responsive search paradigms.

The platform architecture includes an intuitive web interface featuring file uploads, AI-powered search, and visual material representation. AI does not only serve a data structuring function but also significantly enhances user experience (UX), ensuring accessibility and ease of use. The relationship between AI and UX is reciprocal, where AI-driven recommendations and interactive assistance optimize decision-making while a well-designed UX increases AI adoption and effectiveness (Virvou, 2023). By leveraging AI-supported UX methodologies, the system dynamically adapts to changing user needs, facilitating seamless navigation and material exploration (Stige et al., 2023).

Additionally, the backend employs state-of-the-art AI models, such as OpenAI and Llama, to refine data structuring and improve search accuracy. Research indicates that AI-driven UX processes can optimize digital design by automating requirement gathering, enhancing solution development, and refining iterative evaluation (Stige et al., 2023). One of the most significant benefits of this AI integration is the drastic reduction in time required for data input and material discovery. Waste managers can populate the database more efficiently, while designers and manufacturers can quickly identify innovative recycled materials, focusing on creative applications. The API integration with Rhinoceros, a CAD software, further streamlines the workflow for designers and manufacturers.

9. Conclusions

This contribution has described the state of development of a research project that aims to enhance circular material use in the furniture industry, with a particular focus on the role of the designers and their information needs while matching consumer needs and desires with material possibilities as well as regulatory issues and sometimes conflicting stakeholder interests.

The paper started by outlining the Italian furniture value chain in relation with circularity, already subject of several studies and reports, which highlight a developing national (and European) system of sustainable furniture production, but also an increasing complexity that requires significant expertise to navigate. Within the long chain of processes in the life cycle of a furniture, the project chose to focus on the phases of material production and component production, and the designer’s capacity to optimize these steps through informed decision-making upstream. Beyond designers, other key stakeholders such as furniture manufacturers and waste material transforming companies were interviewed, highlighting the sometimes blurry line between them. The resulting insights included three main problematic areas: limited awareness and mistaken perception of circular materials, lack of trust in the quality of environmental impact data about materials, and the difficulty of designing with circular materials and setting up an effective and reliable supply chain. These issues led firstly to identifying guidelines and features for better digital tools, then to the definition of enhanced workflows including the user journey and interfaces, as well as an outline of advanced AI capabilities, which may act as a well-informed “translator” between various professional figures who otherwise have difficulty with collaborating due to the differences in their professional jargons and mindsets.

Although the initial prototypes are promising, the subsequent in-depth experimentation will be necessary to understand the efficacy of the most advanced functionalities, especially the AI assistant that should be trustworthy and intuitive across various interfaces, and CAD Plug-in that should fit into various personal working styles of designers. Future research should also examine whether and how much the tool should change to tackle different geographical areas (e.g. different material parameters due to different regulations) or to tackle other industries beyond furniture. While technical development is still in progress, hopefully the developed knowledge and experiments will contribute to a more effective digital toolbox for designers, allowing them to become leaders of circular transformation and proactive actors who not only do the right design choices, but also help to establish local and circular supply chains.

Notes

1. UNEP (2019). 9R-Framework [Online] Available at: https://www.unep.org/circularity

2. UI KIT Italia | Figma. (n.d.). Figma. https://www.figma.com/community/file/1105848677422572920

References

Arditi, S. (2017). Circular Economy opportunities in the furniture sector (p. 55). European Environmental Bureau (EEB). https://eeb.org/wp-content/uploads/2019/05/Report-on-the-Circular-Economy-in-the-Furniture-Sector.pdf

Bakker, C., Wang, F., Huisman, J., & den Hollander, M. (2014). Products that go round: Exploring product life extension through design. Journal of Cleaner Production, 69, 10–16. https://doi.org/10.1016/j.jclepro.2014.01.028

Barbaritano, M., Bravi, L., & Savelli, E. (2019). Sustainability and Quality Management in the Italian Luxury Furniture Sector: A Circular Economy Perspective. Sustainability, 11, 3089. https://doi.org/10.3390/su11113089

Cecconello, M. A. (2022). Circular Economy Solutions and Strategies for the Furniture Sector in the European Union. Diid — Disegno Industriale Industrial Design, (78), 10. https://doi.org/10.30682/diid7822k

CENFIM (2021). Impacts of the twin transition on the EU furniture industry. Forecast of the sector by 2030 due to its circular economy transition and digital transformation. Final Report of the SAWYER Project. https://circularfurniture-sawyer.eu/wp-content/uploads/2021/03/SAWYER-Final_report-EN.pdf

Corbin, J. M., & Strauss, A. L. (2008). Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory (3° edizione). Sage Pubns.

Cusumano, M. A., Gawer, A., & Yoffie, D. B. (2019). The Business of Platforms: Strategy in the Age of Digital Competition, Innovation, and Power (Illustrated Edition). Harper Business.

Donatello, S., Gama Caldas M. & Wolf, O. (2017). Revision of EU Green Public Procurement (GPP) criteria for Furniture. Technical Report: Final version, EUR 28729 EN, Publications Office of the European Union, Luxembourg, 2017, https://doi.org/10.2760/14246, JRC107824.

EEB (2017). Circular Economy opportunities in the furniture sector (p. 55). https://eeb.org/wp-content/uploads/2019/05/Report-on-the-Circular-Economy-in-the-Furniture-Sector.pdf

Eriksson, K. M., Carlsson, L., & Olsson, A. K. (2022). To digitalize or not? Navigating and merging human- and technology perspectives in production planning and control. The International Journal of Advanced Manufacturing Technology, 122(11), 4365–4373. https://doi.org/10.1007/s00170-022-09874-x

EU Commission. (2020). Communication from the commission to the european parliament, the council, the european economic and social committee and the committee of the regions. A new Circular Economy Action Plan For a cleaner and more competitive Europe. https://eur-lex.europa.eu/legal-content/EN/TXT/?qid=1583933814386&uri=COM:2020:98:FIN

European Commission (2020). A new Circular Economy Action Plan For a cleaner and more competitive Europe, document 52020DC0098, 98 final.

European Commission (2024). Regulation (EU) 2024/1781 of the European Parliament and of the Council of 13 June 2024 establishing a framework for the setting of ecodesign requirements for sustainable products.

Farahmand, S. H., & Rahimiaghdas, N. (2024). Circular Economy and Business Transformation in European Furniture Industry. Proceedings of The International Conference on Business, Management and Economics, 1(1), Articolo 1. https://doi.org/10.33422/icbmeconf.v1i1.207

Jiang, J., Zhou, K., Dong, Z., Ye, K., Zhao, W. X., & Wen, J. R. (2023). Structgpt: A general framework for large language model to reason over structured data. arXiv preprint arXiv:2305.09645.

Kirchherr, J., & Piscicelli, L. (2019). Towards an Education for the Circular Economy (ECE): Five Teaching Principles and a Case Study. Resources, Conservation and Recycling, 150. https://doi.org/10.1016/j.resconrec.2019.104406

McCamish, B., Ghadakchi, V., Termehchy, A., Touri, B., & Huang, L. (2018, May). The data interaction game. In Proceedings of the 2018 International Conference on Management of Data (pp. 83-98).

Moreno, M., De los Rios, C., Rowe, Z., & Charnley, F. (2016). A Conceptual Framework for Circular Design. Sustainability, 8(9), Articolo 9. https://doi.org/10.3390/su8090937

Mura, M., Longo, M. & Zanni, S. (2020). Circular economy in Italian SMEs: A multi-method study. J. Clean. Prod., 245, 118821.

Murray, A. K., Ahlquist, E. T., McKenna, M. K., & Debs, M. (2023). The Bloomsbury Handbook of Montessori Education. Bloomsbury USA Academic.

Nilsson-Lindén, H., Baumann, H., & Rex, E. (2019). LCM development: Focusing on the LC promoters and their organizational problem-solving. The International Journal of Life Cycle Assessment, 24(2), 297–309. https://doi.org/10.1007/s11367-018-1523-z

Pieroni, M. P. P., McAloone, T. C., & Pigosso, D. C. A. (2019). Business model innovation for circular economy and sustainability: A review of approaches. Journal of Cleaner Production, 215, 198–216. https://doi.org/10.1016/j.jclepro.2019.01.036

Potting, J., Hekkert, M. P., Worrell, E., & Hanemaaijer, A. (2017). Circular Economy: Measuring innovation in the product chain.

Reike, D., Vermeulen, W.J.V., Witjes, S. (2018). The circular economy: New or Refurbished as CE 3.0? — Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options. Resources, Conservation and Recycling, 135, 246-264, https://doi.org/10.1016/j.resconrec.2017.08.027.

ReMade (2024), Certified products Catalogue. [Online] Available at: https://www.remadeinitaly.it/catalogo-remade/

Safdar, M., Yasmin, M., & Anwar, B. (2021). English for specific purpose through facilitated and nonfacilitated MOOCs: An analysis of the learners' perspectives. Computer Applications in Engineering Education, 29(4), 786–794. https://doi.org/10.1002/cae.22246

Savelli, E., Barbaritano, M., Bravi, L. (2019). Circular Economy and Quality Management within the Furniture Sector: an exploratory study. Proceedings of the 1st Conference on Quality Innovation and Sustainability – ICQIS2019 – Valença (Portugal) – June 2019, 61-71.

Schilling-Wilhelmi, M., Ríos-García, M., Shabih, S., Gil, M. V., Miret, S., Koch, C. T., ... & Jablonka, K. M. (2024). From text to insight: large language models for materials science data extraction. arXiv preprint arXiv:2407.16867.

Silvius, G., Ismayilova, A., Sales-Vivó, V. & Costi, M. (2021). Exploring Barriers for Circularity in the EU Furniture Industry. Sustainability, 13, 11072. https://doi.org/10.3390/su131911072

Stige, Å., Zamani, E. D., Mikalef, P., & Zhu, Y. (2024). Artificial intelligence (AI) for user experience (UX) design: a systematic literature review and future research agenda. Information Technology & People, 37(6), 2324-2352.

Symbola Foundation & Enel (2021). 100 Italian Circular Economy Stories. Available online at: https://www.symbola.net/ricerca/100-italian-circular-economy-stories/

Symbola Foundation & Federlegno Arredo (2016). Il Made in Italy abita il futuro. Il Legno Arredo verso l'economia circolare. Available online at: https://symbola.net/ricerca/il-made-in-italy-abita-il-futuro-il-legno-arredo-verso-leconomia-circolare/

Vindrola-Padros, C., & Johnson, G. A. (2020). Rapid Techniques in Qualitative Research: A Critical Review of the Literature. Qualitative Health Research, 30(10), 1596–1604. https://doi.org/10.1177/1049732320921835

Virvou, M. (2023). Artificial Intelligence and User Experience in reciprocity: Contributions and state of the art. Intelligent Decision Technologies, 17(1), 73-125.

About the Authors:

Viktor Malakuczi PhD, Assistant Professor in Design at Sapienza University of Rome. His research interests that revolve around the contamination of Design with advanced digital know-how. The three main threads of research are design for digital manufacturing, design for cultural experience and design for internet of things.

Luca D'Elia (PhD) is a designer and Researcher at the PDTA

Department of Sapienza University of Rome. His Research activity focuses on digital manufacturing and co-design practices in urban context and within the Makers community.

Carmen Rotondi Product Designer and Ph.D., she conducts research in Industrial Design (ICAR/13) on Biodesign and Biofabrication and, more generally, on the hybridization between design and science, nature and artifice. Her PhD thesis focused on the new concept of "Bio-Augmented Materiality" fostered by bio-digital practices and aimed at innovating through the contemporary eco-entangled context.

Paola Altamura Architect, PhD in Environmental Design, Tenure Track Researcher at Sapienza University, former Research Fellow at ENEA. She conducts research and experimentation on the built environment's sustainable transformation with a life-cycle approach, focusing on material resource efficiency and circular design strategies.

Mariia Ershova PhD student in Service Design for Public Sector at the Sapienza University of Rome. Research Fellow in Made in Italy Circolare e Sostenibile. SID Research Award 2024 for Research ideas. Main interests: Digital twin, and Embodied design methods.

Gabriele Rossini Architect, PhD student in Environmental Design at the PDTA Department of Sapienza University of Rome, Research Fellow on a NPRR project. His research activity concerns material resources circularity in architecture, focusing on the hybridization of biological and technical materials.

Alessandro Aiuti PhD student in Service Design for Public Sector at Sapienza University of Rome. His work investigates how HCI and service design can transform urban mobility and sustainably regenerate public spaces, fostering more accessible and resilient cities.

Sabrina Lucibello Architect and Ph.D., she is Associate Professor at the Department Planning, Design and Technology of Architecture of the Sapienza University of Rome. She is president of the Degree in Design and director of the Saperi&Co. research centre. She carries out research in Industrial Design (ICAR/13) on the subject of product innovation through materials for design.

Serena Baiani Associate Professor of Technological and Environmental Architectural Design at Sapienza, she conducts research on the relationship between existing buildings' design/technological innovation/ecological and energy efficiency in national and European research, focusing on life-cycle approach and heritage adaptive reuse in fragile contexts.

Emanuele Panizzi Associate Professor in Computer Science at Sapienza University of Rome, Italy. He directs a research team focusing on human-computer interaction, app design, gamification, and context-aware mobile interaction.

Lorenzo Imbesi Full Professor of Design at Sapienza University of Rome, where he is the former Director of the Sapienza Design Research Interdepartmental Centre and the Coordinator of the PhD in Service Design for Public Sector. He is also the President of Cumulus Association, President of the Italian Scientific Society of Design (SID), and member of the Executive Committee of the European Academy of Design (EAD).

Acknowledgements: This study was carried out within the MICS (Made in Italy – Circular and Sustainable) Extended Partnership and received funding from the European Union Next-GenerationEU (PIANO NAZIONALE DI RIPRESA E RESILIENZA (PNRR) – MISSIONE 4 COMPONENTE 2, INVESTIMENTO 1.3 – D.D. 1551.11-10-2022, PE00000004). This manuscript reflects only the authors' views and opinions, neither the European Union nor the European Commission can be considered responsible for them.