Perceiving New Sustainable Materials. Perceptual And Sensory Analysis Of Transparent Wood And Its Competitors

Università di Genova | DAD DIPARTIMENTO ARCHITETTURA E DESIGN

# Circular design in Action: practices, networks, education and research

## Exploring the role of community and education in driving action-oriented research and practical innovation


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Co-funded by the European Union


CiD circular design

**Proceedings of the Conference „Circular design in action: practices, networks, education and research - Exploring the role of community and education in driving action-oriented research and practical innovation“.**
Conference in Genova, 22-23 May 2025
„Circular Design Education“ conference
from **CiD Erasmus+ Project** - www.cid-innovationalliance.eu

***conference organized by***
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*The papers in these proceedings were selected through an open call and underwent double-blind peer review.*

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Federica Delprino, Francesca Costanzo

***published by:***
Regionales Bauen und Siedlungsplanung, Leibniz Universität Hannover
Herrenhäuser Str. 8, D-30419 Hannover
**ISBN 978-3-946296-55-3**
www.staedtebau.uni-hannover.de/en/territorial-design-and-urban-planning/

Co-funded by the European Union, Erasmus+ Innovation Alliance, Grant 101111686.
Published in the framework of CiD Circular Design Innovation Alliance.

**The Innovation Alliance Circular Design (CiD) offers a radically new model on how to link design to circularity and urban transformation. The Alliance aims to establish benchmarks for rethinking design in a circular economy, shifting urban design, architecture, product and service design towards carbon-neutral cities, and enhancing bio-based innovation for building.**

**Blueprints for green, resilience, and digital skills are to support the change towards sustainable, inclusive, affordable cities. They boost the turn to a circular construction and design econ my driven by culture and creativity.**

**CiD operates on three levels: the co-creation of knowledge on circular design, the set-up of an innovation ecosystem for circular design, and educational innovation in academia, green entrepreneurship, and continuous learning and upskilling.**

**The CiD Innovation Ecosystem brings together relevant actors from academia, research, business incubators, continuous education, civil society organisations, and enterprises. The evolution of the Alliance's results, their dissemination and sustainability beyond the project is supported through the involvement of Europe-wide organisations in architectural practice, society, and culture.**

**Local and Europe-wide observatories set up within CiD aim at including relevant stakeholders to connect the education and research environments with the surrounding socio/economic environment. The Observatories will contribute to the framework of challenges for the co-creation and flow of knowledge and to novel models for challenge-based education.**

# Circular design in Action: practices, networks, education and research

**Exploring the role of community and education in driving action-oriented research and practical innovation**

The Circular Design in Action: Practices and Research conference - organized by Department Architecture and Design of University of Genova - invites scholars, researchers, designers, and practitioners to share their insights and innovative approaches in circular design. This event is part of the CiD Project – Circular Design for Bio-based Innovation towards Climate-Neutral Cities, an initiative fostering sustainable solutions in architecture, product design, and urban transformation.
In an era of pressing environmental challenges, design plays a fundamental role in shaping a sustainable future. The conference will explore circular economy principles, bio-based materials, and innovative design methodologies that drive the transition toward carbon-neutral cities. Participants will have the opportunity to showcase research, methodologies, and practical applications that redefine how materials, products, and built environments are designed, produced, and regenerated, within two tracks:
+ Track 1: Design for change
+ Track 2: Circular Cities

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# 5.1 Perceiving New Sustainable Materials

## Perceptual And Sensory Analysis Of Transparent Wood And Its Competitors

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**KEYWORDS** | #Materials #SSbD #TransparentWood #Senses #Materials library

**1. Introduction and research context**

Transparent Wood (TW) is an innovative material with potential applications in construction, automotive, electronics, and interior design, as well as a sustainable alternative to plastics and glass (Mariani & Malucelli, 2022). TW is obtained by delignifying natural wood and infiltrating it with bio-resin or bio-plastic. These materials have a similar refractive index to the hosting materials, which makes the wood transparent (Mariani & Malucelli 2022). The result is a perceptual hybrid with qualities that differ from both the original material and the materials it emulates, such as plastic or glass. The AI-TranspWood project, a three-year Horizon Europe initiative, aims to develop AI-driven methods for designing and manufacturing TW composites under the EU's „Safe and Sustainable-by-Design" framework. The aim of this approach is to guide the innovation process for chemicals and materials in a clean and sustainable way (European Commission. Joint Research Centre, 2023).
The project involves international collaboration between universities, research centres, and companies, with the goal of boosting Europe's leadership in TW production. A research team from Politecnico di Torino leads the project's Dissemination and Communication work packages, ensuring effective communication of findings and stakeholder engagement. Devoting the right amount of attention to communicating the identity of this new material and its unique qualitative aspects is indeed crucial for its market diffusion (Hornbuckle 2018). Indeed, the successful diffusion of new materials depends not only on their technical properties (chemical, physical or mechanical), which are of interest to industry and technicians, but also on how they are perceived and experienced by end users.

Taking a sensory approach to testing materials, considering for example texture, colour, sound effects, and temperature is crucial for guiding a product satisfaction (Karana et al., 2014). Therefore, sensory and perceptual analysis of TW was conducted to answer the following research question (RQ): How to promote the adoption and dissemination of TW among stakeholders and civil society despite the expectation about native wood and clear plastic?
The sensory and perceptual analysis followed a specific protocol derived from scientific literature, evaluating 5x5 cm samples of TW alongside its direct competitors: wood and transparent plastic. Eighty voluntary participants, referred to as "materials testers," took part in a two-hour workshop where they described material samples using adjectives relating to three senses: sight, hearing and touch. The research results provide a sensory and perceptual comparison of the three materials. These results are of interest to multiple users from both industry and academia. Project partners will gain valuable insights into TW samples development, project professionals will receive qualitative details on the identity of transparent wood that they can use for their future projects, and finally researchers may find the methodology useful for promoting the acceptance of new sustainable materials that are not yet available on the market.

**2. What Transparent wood is**

Transparent wood is an innovative material, first obtained by Siegfried Fink at the beginnings of 90', (Fink, 1992) developed by chemically removing lignin, the component responsible for wood's colour and opacity, from natural wood. This process leaves behind a porous, white cellulose structure, which is then infiltrated with a transparent polymer, such as poly(methyl methacrylate) (PMMA), whose refraction index perfectly matches that of the hosting material, to achieve optical transparency. The resulting material maintains the mechanical strength of natural wood while allowing light to pass through, making it a promising, sustainable alternative to traditional materials like glass and certain plastics. Transparent wood was not significantly studied from the 1990s until 2015. It re-emerged in 2015 when two independent research teams from USA (Zhu et al. 2016) and Sweden (Li et al. 2016) revisited Fink's methodology. They investigated the properties and potential applications of Transparent Wood, leading to significant advancements in its development. Since then, research and into transparent wood has accelerated: the so obtained material shows high optical transmittance, lightness, toughness, flexibility or stiffness, durability, and specific thermal properties (low thermal conductivity), among others. Transparent wood is also an interesting material because of its sustainability. It is derived from renewable resources, and the polymer matrix can be sourced from biodegradable or recyclable materials. Compared to glass or plastic, TW produces fewer carbon emissions during manufacturing, resulting in a smaller environmental footprint (Chutturi et al. 2023).

Transparent wood (TW) offers a combination of mechanical strength, optical transparency and sustainability, making it a promising alternative to glass, plastic and composite materials. In architecture, TW offers excellent insulation and light transmission for windows and façades, thereby improving a building's energy efficiency (De Ranieri, 2016). Its high strength-to-weight ratio enables the construction of lightweight structures for use in the automotive and aerospace industries, thereby reducing fuel consumption (Wu et al., 2024). In energy storage and solar technologies, TW enhances battery performance and solar cell efficiency thanks to its light-guiding and conductive properties (Zhu et al., 2016). Finally, TW's flexibility and durability make it ideal for next-generation electronics and optoelectronics, such as flexible displays, wearable devices, LEDs and transparent circuits, enabling more sustainable, high-performance technologies (Wan et al., 2021).

**3. Material's sensorial perception**

Materials are essential in shaping both the functionality and identity of products, and since the 2000s, the perceived qualities of materials have been considered as important as their performance (Ashby et al., 2014). Design has followed this line of research, and over the years, various methodologies and frameworks have been developed to explore material perception (Miodownik 2017, Giaccardi & Karana 2015, Sakamoto & Watanabe 2017).
As consumers seek more immersive experiences, the sensory properties of materials (Gessinger, 2009), visual, auditory, and tactile, play a key role in user engagement and perception. Thoughtful material selection ensures that products are not only practical but also emotionally, aesthetically compelling, and meaningful user experiences (Karana et. al, 2015).

Visual perception is the primary way materials are evaluated. Colour, texture, opacity, and reflectivity influence user expectations and emotions (Lerma et al., 2013). For example, glass can appear fluid, fragile, or cold depending on its processing, while matte and glossy finishes convey different impressions, from luxury to subtlety. Additionally, materials can tell a story about their origin: recycled materials often retain visible traces of their past, adding uniqueness and reinforcing sustainability narratives.

Sound also significantly impacts material perception. The way a material absorbs or reflects sound contributes to its identity, sometimes even becoming a recognizable brand feature. A precise click of a luxury handbag clasp or the distinct snap of a lipstick case enhances user satisfaction and product appeal. Thoughtfully designed sound profiles can influence consumer trust and create a familiar sensory experience, strengthening brand recognition (Dal Palù et al. 2018).
Touch is one of the most intimate ways people interact with materials. Textures and surface qualities—such as smoothness, roughness, flexibility, or rigidity—affect comfort, usability, and desirability. Natural materials like wood feel warm and authentic, while soft-touch coatings

on electronics and packaging add a premium, velvety sensation. Additionally, material selection influences ergonomics; textured surfaces improve grip, while flexible materials enhance comfort in wearable products (Allione et al. 2012). Ultimately, materials do more than serve technical functions—they shape sensory experiences and emotional connections.
By considering the interplay between sight, sound, and touch, designers can create products that are both practical and deeply engaging, enhancing user interaction and brand perception (Spence & Gallace, 2011).
Transparent wood serves as an ideal example of the usefulness of sensory analysis. Indeed, transparent wood can be considered a perceptually ambiguous material (Cheeseman et al., 2022), as it simultaneously resembles plastic or glass on a visual level and wood on a tactile level. These inconsistencies have the potential to slow the adoption of the material, as they create a novel and unexpected material identity for the end user.

## 4. Testing material's sensorial perception

The research aims to identify the key sensory characteristics of transparent wood and its main competitors: natural wood and transparent plastic. There are established methods for analysing qualitative sensory aspects, as well as standardized approaches to enhance the effectiveness of the process (Dal Palù et al. 2017).

One such method is the use of sensory vocabulary—a structured list of adjectives categorized by sensory modality, including sight, hearing, and touch (Sakamoto & Watanabe, 2017; Houix et al., 2012). These carefully selected descriptors facilitate the qualitative sensory perception analysis of samples, and is the method chosen to answer the following research question:
*How to promote the adoption and dissemination of Transparent Wood among stakeholders and civil society, despite the expectation about native wood and clear plastic?*

The research used a standardised protocol involving 80 voluntary participants, evenly distributed by gender with an average age of 23 years. The protocol involved analysing transparent wood, natural wood and plastic (PMMA) samples using the senses of sight, hearing and touch. The participants had to perform three separate actions for each sense, for a total of nine consecutive actions. For each action, participants were required to select a maximum of four adjectives from the sensory vocabulary list (Table 1) to describe their perception of the material.

For each adjective, its definition or a practical example were given (e.g. "Pale: A pale light or colour is not bright or strong"). Participants were asked to choose a maximum of four adjectives they considered to be the most relevant by performing a specific action for a set amount of time.

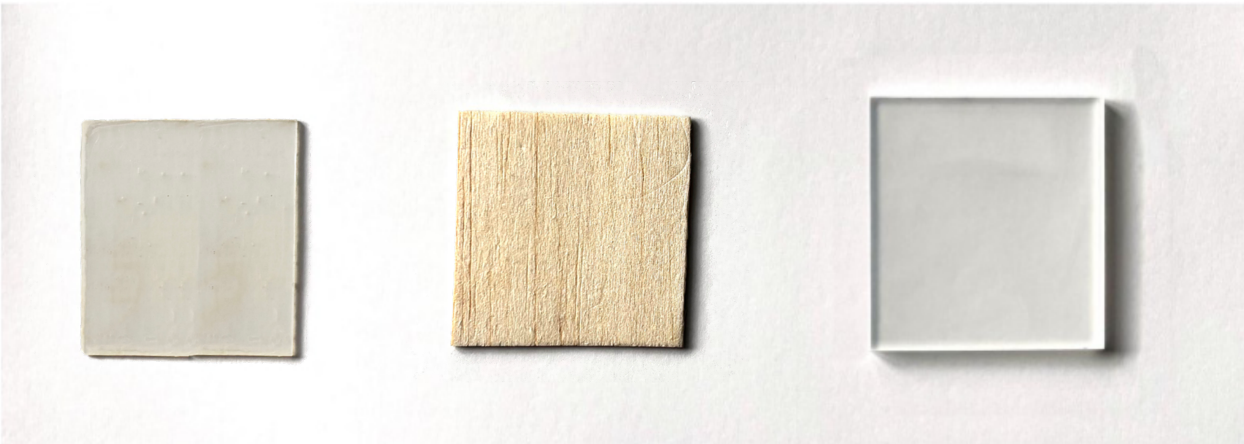

Figure 1: Samples of Transparent Wood, conventional wood and plastic (PMMA)



| Sight | Touch | Hearing |
|---|---|---|
| Vivid | Warm | Dull |
| Intense | Cold | Irregular |
| Warm | Hard | Penetrating |
| Bright | Soft | Strident |
| Clear | Rough | Harsh |
| Sparkling | Smooth | High-pitched |
| Delicate | Slippery | Low |
| Mellow | Sticky | Mild |
| Faded | Shape memory | Deep |
| Dull | Fibrous | Subtle |
| Pale | Rigid | |
| Opaque | Flexible | |

Table 1: Sensory Vocabulary used during the analysis

For the first sense, sight, the following three specific actions were carried out:
1. Place the sample on top of the printed sheet of paper and move it without detaching it from the sheet – 30 seconds.
2. Place the sample in backlight (first natural and then artificial) – 30 seconds.
3. Rotate the sample to make it vertical, horizontal, oblique – 30 seconds.

For the hearing, the following three specific actions were carried out:
4. Tap the sample with your knuckles, with a pen or a marker (in plastic like a Bic) – 30 seconds.
5. Wave the sample – 30 seconds.
6. Scratch the sample with your fingernail – 30 seconds.

For the touch, three specific actions were carried out:
7. Thermal perception: place your hand on the table for 10 seconds, then place it on the sample for 3 seconds – 13 seconds.
8. Run your finger over the sample in circular movements – 30 seconds.
9. Handle the sample, try to bend it – 30 seconds.

The collected data were then systematically analysed both within each sensory category and across multiple sensory modalities (cross-sensory analysis). This approach allowed for a comprehensive understanding of how the different materials were perceived holistically, identifying potential correlations between sensory attributes such as texture and appearance or sound and touch.
A total of about 2,800 adjectives were collected to describe the wood, transparent wood and plastic (PMMA) samples according to three senses, with three actions performed for each sense. For analysis purposes, they were entered into a spreadsheet and subdivided by sense and action.
A heat chart was then created to show the most and least frequently used adjectives.

## 5. Findings

The reported results are the outcome of a cross-sensory analysis among the three different materials, selecting three actions:
- Sight_Action 3 - Rotate the sample to make it vertical, horizontal, oblique
- Hearing_Action 1 - Tap the sample with your knuckles, with a pen or a marker
- Touch_Action 2 - Run your finger over the sample in circular movements

The three actions were not chosen at random: when analysed together, they reveal the behaviour of transparent wood in relation to light, objects and human interaction.
As anticipated in the previous chapter, to detect correlations and the popularity of adjectives, the heat chart was chosen. The colours in the box indicate how frequently the adjective was chosen: the closer the colour is to beige, the less frequently the adjective was chosen, and the closer it is to dark blue, the more frequently it was chosen. The number of boxes shows how many times the adjective was used. This enables a visual and numerical comparison.
Beyond the evidence from individual graphs, considerations were drawn by cross-referencing the results of the three graphs. The considerations below are based on the intersection of the dark blue and dark blue areas within the different senses.

First, Wood is perceived as the most vivid and intense sample, with the deepest sound. It is also perceived as warmer than Transparent Wood visually, while in terms of touch, Wood and Transparent Wood are perceived as equally warm. At sight, all three materials appear delicate, and all samples produce low and mild sounds. Wood is the most fibrous sample to the touch, but Transparent Wood is still considered very fibrous. However, Transparent Wood is perceived as less rough than Wood but rougher than Plastic from a hearing perspective. Transparent Wood appears more sparkling than Wood and Plastic visually and produces higher-pitched sounds than both.

## 6. Discussion and conclusions

The sensory and perceptual analysis of materials is widespread in the Design disciplines (Allione et al., 2012). However, this is the first study to focus specifically on the perception of Transparent Wood and its competitors, i.e. native wood and clear plastic. Therefore, there is no directly comparable data.
The sensory perceptual analysis shows that TW can be considered as a perceptually ambiguous material (Cheeseman et al., 2022) because it has a cross-sensory identity that goes beyond normal material classification.
The research has a direct impact on multiple groups: project partners, researchers and project professionals. By integrating the insights derived from the perceptual and sensorial, partners of AI-TranspWood project could better assess the expressive potential of Transparent Wood samples, guiding its development, facilitating the narrative about its sustainability and optimizing its sensory appeal for widespread adoption.
Researchers have developed a methodology for analysing material samples, particularly for comparing innovative and traditional materials.

Finally, project professionals will benefit from the results, which will help them to discover the identity of a new material that may be on the market in the future, and how to exploit it in a project.
Studies investigating the differences in the sensory perception of Transparent Wood samples and speculation about his possible new name between Scandinavian and Mediterranean countries are ongoing. Understanding how the new material (TW) is perceived by different populations with diverse and distant cultures can help researchers better define which qualities of the material to highlight and how to develop communication and exploitation activities to maximise its potential future market diffusion.



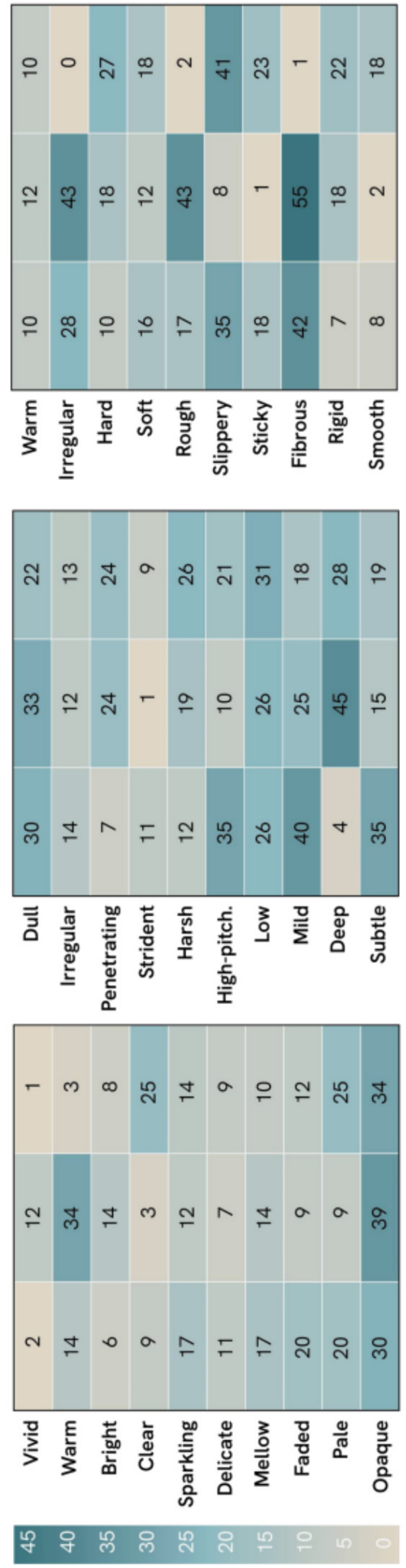


Figure 2: Heat chart regarding Transparent Wood (TW), wood (W), and plastic (P) and corresponding actions

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