TECO®, A BIO-BASED MATERIAL SOLUTION FOR INTERIOR ARCHITECTURE, VALORIZING COFFEE GROUNDS, TEA WASTE AND INDUSTRIAL WOOD OFFCUTSTE

JIMENA ALARCÓN CASTRO, ROSARIO VILLEGAS CABRERA, RICCARDO BALBO AND KONSTANZA NAVARRO ORTÍZ

SUMMARY

The depletion of fossil resources and the increase in pollution due to the materials used in construction have a negative impact on the environment. To mitigate this impact, the development of bio-based materials presents an attractive alternative. The main objective of this research is to design a bio-based panel incorporating Municipal Solid Waste (MSW) and Industrial Solid Waste (ISW) from the wood sector, providing an alternative to traditional construction materials. The methodology consists of three stages: a) Identification and selection of MSW and ISW generated in Concepción, Chile; b) Development of a bio-based material prototype; c) Proposal for applications. The result is Teco®, a composite panel designed for use as cladding in interior architecture, made from a mixture of coffee grounds and tea waste, covered with wood offcuts from furniture manufacturing. Teco® has the potential to be reintegrated into the biological cycle as compost, promoting a continuous cycle from nature to nature. The conclusions focus on the validity of the DIY process to explore alternatives that democratize the ideation and manufacturing of bio-based materials, prioritizing the use of local waste.

Introduction

Globally, the construction of civil works and buildings accounts for 60% of the raw materials extracted from the lithosphere. Of this volume, building construction represents 40%, equivalent to 24% of global extractions. The building construction industry significantly contributes to greenhouse gas emissions, accounting for 37% of global energy-related emissions. Approximately 10% of these emissions are associated with the characteristics of construction materials, which consume large amounts of energy during production and release pollutants into the environment, thereby exacerbating the greenhouse gas emissions of buildings (Siciliano, 2023; Koh *et al*., 2022; Anh *et al*., 2022). With the growing evidence of climate change, waste generation, pollution, and environmental degradation, the consumption of environmentally harmful materials is increasingly scrutinized, as it contradicts the principles of sustainability

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(Tyagi and Kumar, 2021). Current approaches to material design reflect a heightened global awareness of energy dependency and its adverse effects on the economy and quality of life (Happaerts, 2014; Mishra *et al*., 2019). The primary challenge lies in developing innovative material solutions to prevent overexploitation of existing resources and reduce the environmental impact of conventional materials. Several initiatives have been undertaken in this area (Karana *et al*., 2023; Alarcón *et al*., 2017).

One promising alternative is bio-based materials, which are derived partially or entirely from renewable resources, such as plants, algae, or organic waste, rather than fossil-based resources like petroleum (Laamanen and Kääriäinen, 2022; Kamali and Khodaparast, 2015; Ebrahimian *et al*., 2020; Santagata *et al*., 2021). New materials must be environmentally empathetic and durable throughout their lifecycle, while meeting sustainability standards in response to stricter environmental regulations and increasing consumer awareness (Scheunemann *et al*., 2015; Ishii *et al*., 2012).

The World Bank estimates that global annual waste production is currently 2.01 billion metric tons, with a potential increase to 3.4 billion metric tons by 2050 (Kaza *et al*., 2018). Around 40% of waste is disposed of without any subsequent processing, posing significant risks to human health and the environment by contaminating air, water, and soil, as well as facilitating the spread of diseases. Waste management in Chile is a pressing issue. One of the main strategies implemented in this area is the valorization of waste as raw material. Chile's National Organic Waste Strategy 2040 aims to increase the recovery of organic waste generated at the municipal level from the current 1% to 66% by 2040. The strategy emphasizes the need to develop infrastructure, equipment, and logistical systems to enable efficient use of these materials (Ministerio del Medio Ambiente de Chile, 2020). According to the Seventh State of the Environment Report, more than 18 million metric tons of waste were generated in 2020. Of this, 96.7% corresponded to non-hazardous waste, with 50.8% originating from industrial sources and 43.6% from municipal sources (Volta, 2023).

Municipal Solid Waste (MSW) refers to waste generated in urban and rural areas from household, commercial, and institutional activities, and sometimes includes waste from public spaces, while Industrial Solid Waste (ISW) refers to waste generated by industrial processes (Ministerio del Medio Ambiente, 2020). After coffee consumption, spent coffee grounds (SCGs) are usually thrown away and eventually end up in landfills. In recent years, technologies and policies have been actively under development to change this century-old practice, and to develop SCGs into value-added energy and materials. Coffee is the world's second most traded good, only next to oil, and it is the world's second largest beverage, only next to water. The world's coffee consumption in 2020/2021 was nearly 10 million tonnes, with an annual increase of about 1% since 2017 (ICO, 2021). Up to 50% of the SCGs are produced on small scales by coffee shops, restaurants, cafeterias, or individuals, while large-scale SCG producers are mostly from soluble coffee production (Taifouris *et al*., 2021). Only about 30% of the coffee bean's mass can be extracted into the coffee drink, thus a larger fraction ends up as spent coffee grounds, which have been mainly disposed of as waste. Moreover, along with the increasing consumption of tea and its extracts, the amount of tea waste grows rapidly, which not only results in huge biomass loss, but also increases environmental stress (Johnson *et al*, 2022). In past years, interest has been attracted to the utilization of tea waste biomass, and a lot of work has been carried out. Tea waste is a widespread, accessible, and low-cost agricultural bioresource (Guo *et al*, 2021). Since tea is a heavily consumed product worldwide, the large-scale manufacturing of tea is very crucial in the industry. Therefore, the removal of a high quantity of tea waste, which is nearly 4.0% of the produced tea, has gained importance due to environmental concerns (Debnath *et al*, 2021). The wooden furniture manufacturing industry in Concepción, Chile, generates a significant amount of waste. For instance, the company CIC produces approximately 65 tons of waste per month, 90% of which consists primarily of wood (Compañía Industrial y Comercial, 2021).

Recycling and reuse trends associated with material design suggest a paradigm shift in ideation processes, prioritizing the productive value chain and environmental sustainability (Blanpain *et al*., 2016; Caliendo *et al*., 2019; Sauerwein *et al*., 2017; Brañes *et al*., 2023). The third-wave Do It Yourself (DIY) approach (Fox, 2014) integrates knowledge, skills, and methodologies from diverse disciplines, combining them innovatively to create new solutions aligned with circular economy principles, such as recycling materials and products as many times as possible (Wastling *et al*., 2018; Ilyas *et al*., 2023). This approach merges personal creation and fabrication in workshop settings that utilize manual tools, CAD systems, and additive or subtractive manufacturing technologies (Beltagui *et al*., 2020; Franz and Pearce, 2023). It is characterized by the use of accessible tools, such as low-cost 3D printers, open-source software, and home-based experimentation techniques, highlighting its adaptability and ability to deliver localized and context-specific solutions. The focus is on the development of functional prototypes and immediate solutions (Rognoli and Ayal—García, 2021). The DIY methodology encourages experimentation based on practical knowledge, the use of readily available materials, and rapid iterations. Materials created within this framework often reflect the identity of the region where they are produced, as they are made using local raw materials, techniques, and resources (Barati *et al*., 2019).

Methodological Approach

The proposed methodological approach highlights an alternative for adding value to Municipal Solid Waste (MSW) and Industrial Solid Waste (ISW) by transforming them into raw materials, thereby minimizing waste generated through consumption (Matiacevich, 2023). This methodology was developed in three stages, incorporating the principles of sustainable design, waste valorization, and the third-wave Do-It-Yourself (DIY) approach (Fox, 2014). In the first stage, titled 'Identification and Selection of MSW and ISW generated in Concepción, Chile', this process involved analyzing their composition, availability, and technical characteristics (Figure 1). For the design of a bio-based material, waste from tea and coffee consumption, along with wood offcuts from furniture manufacturing, were selected. The second stage, 'Development of a Bio-Based Material Prototype', implemented the DIY approach as a method for creating the bio-based material. This stage considered its potential to democratize manufacturing, optimize the use of local resources, and promote innovation. The process highlights the potential of DIY to foster material solutions with a sustainable approach that is contextually grounded in the local environment. The third and final stage, 'Application Proposal', consists of creating a catalogue of applications for Teco® to be used in interior architecture.

Materials and Methods

Identification and selection of MSW and ISW generated in Concepción, Chile

For this study, a mapping of companies within the wooden furniture

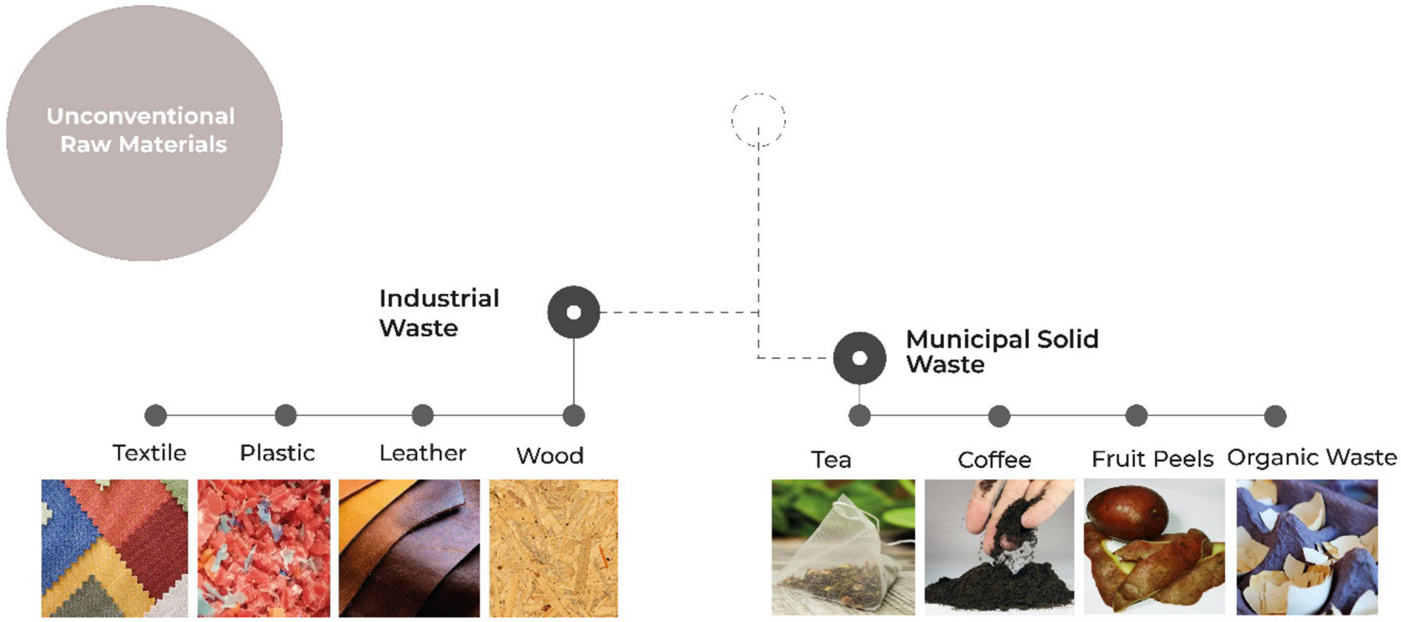

Figure 1. Waste identified and classified according to its industrial or domestic origin.

manufacturing sector was conducted using the database available on the Chilean Internal Revenue Service's website. A total of 27 companies were identified, representing the top 30% in terms of sales volume within the sector. Subsequently, the websites and social media profiles of these companies were analyzed to examine the types of materials utilized, the products manufactured, and the production processes implemented. Based on this preliminary analysis, six companies were selected for in-depth fieldwork.

The field study focused on variables such as the types of wood used in furniture manufacturing, as well as the quantity and quality of the offcuts generated during production. Specific characteristics of the offcuts were analyzed, including the wood species, dimensions, and visual properties. The physical-mechanical properties of the wood were not examined, as the materials used in furniture manufacturing comply with the quality standards established by current regulations. Furthermore, the compatibility of wood offcuts with machining processes, such as cutting and milling, was evaluated.

The findings revealed that 70% of the offcuts exhibit irregular dimensions but can be adjusted to standardized formats with maximum dimensions of 300 x 300mm and thicknesses ranging from 10 to 12mm. The most commonly used wood species in the manufacturing processes were identified as Raulí (*Nothofagus alpina*) and Radiata Pine (*Pinus radiata* D. Don).

In relation to Industrial Solid Waste (ISW), a mapping of municipal collection points was conducted, delineating territorial routes that encompass food service areas and residential neighborhoods. Waste streams with the highest potential for reuse were selected based on criteria such as high availability, efficient collection systems, and organized distribution to treatment facilities. Additionally, the suitability of these waste materials for processing using manual or low-tech production techniques was considered.

Development of a bio-based material prototype

An experimental process was conducted to design a bio-based material aimed at contributing to the closure of production cycles and reducing waste, utilizing the third-wave Do It Yourself (DIY) approach. From a technical development perspective, the process included weighing components (tea, coffee, and beeswax), creating mixtures with varying component ratios, applying a hot press, and machining (Figure 2). Tea and coffee residues were dried to reduce moisture content, enhancing the adhesion between the particles and the beeswax used as a binder. Lower moisture levels were found to reduce drying and baking times. The tea and coffee particles agglomerated effectively, forming a dense, smooth, and durable surface layer. The hydrophobic property of beeswax provided the substrate with a layer of impermeability and protection. The proportion of the substrate components was established as 25% tea waste, 55% coffee grounds, and 25% beeswax. Wood offcuts were utilized to encase the substrate, forming a sandwich panel structure. Accessible tools from the third-wave DIY approach were employed, including low-cost 3D printers for prototyping and testing the visual appearance of the wooden faces. Computer-aided design (CAD) systems were used to create perforations, while electric saws were utilized to cut the wooden faces into square panels measuring 300 x 300mm. To define the visual appearance of the wooden faces, a selection of natural references was carried out to serve as inspiration. Attributes such as containment, encapsulation, protection, and visual dynamics based on lines and volumes were identified. Sketches were created to conduct a graphic process of formal synthesis based on these natural references (Figure 3).

The material's pattern and aesthetic were defined to reveal the substrate through perforations, allowing users to perceive the aromatic and functional qualities offered by the combination of tea residues, coffee grounds, and beeswax. The resulting material exhibits a handcrafted and imperfect appearance due to the low-tech manufacturing process and the use of manual techniques, which are characteristic of DIY materials (Rognoli *et*

Figure 2. Teco ® manufacturing process.

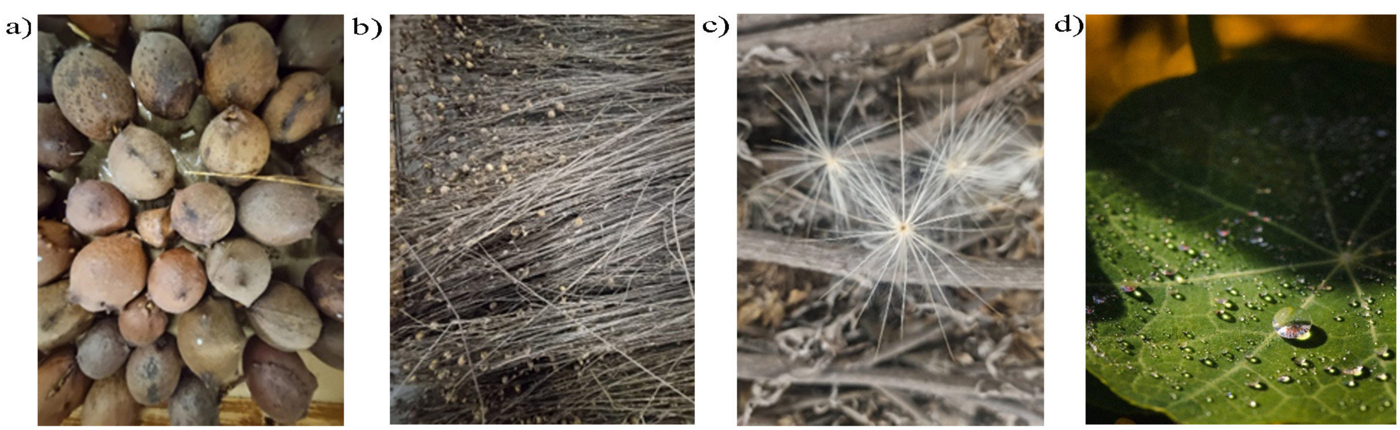

Figure 3. Natural references and inspiration to define the appearance of the wood faces. a: Encapsulation, protection, b: dynamics of strokes and spheres, c: protection, contrast, volume and lines, d: containment, dynamics of strokes and spheres.

al., 2021; Ayala-García *et al*., 2017; Alarcón *et al*., 2020) (Figure 4).

Applications proposal

The inclusion of an Applications Proposal section in this study aims to connect the technical development of the Teco® panel with its applicability in real-world environments. This demonstrates the material's feasibility in architectural projects and encourages its adoption in the design and interior architecture (Figure 5). Furthermore, this section democratizes knowledge by offering concrete examples that make it easier for users, designers, and architects to incorporate Teco® into their projects, reducing barriers to the use of innovative materials. Additionally, these proposals validate the functionality and aesthetics of the material, showcasing its ability to replace traditional options with technical, economic, and ecological advantages. Finally, this approach inspires new ideas to expand the panel's range of uses in various architectural contexts, promoting innovation and highlighting its value as a contemporary solution.

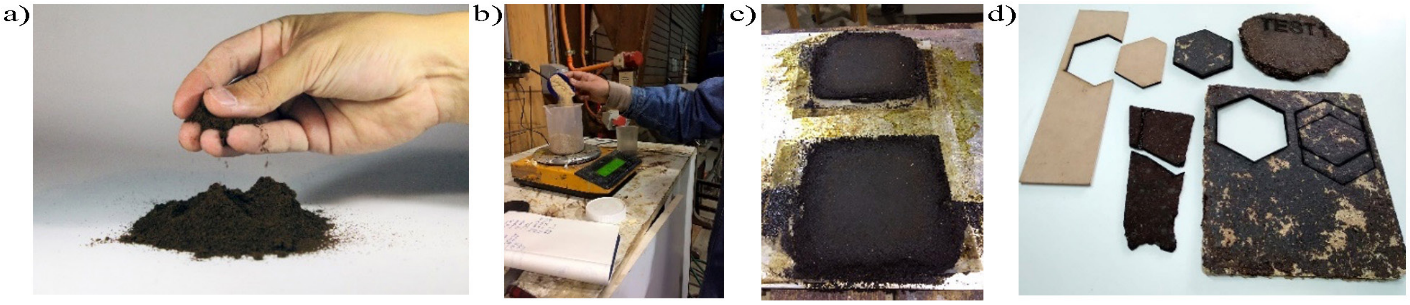

Figure 4. Production process summary. a: Coffee grounds, b: Weighing of components, c: Pressing of the mixture, d: Experimenting with cuts to the substrate.

Figure 5. Teco ® application example.

Results

The outcome of this research is Teco®, a composite panel composed of a substrate derived from waste produced by tea and coffee consumption, bound with beeswax as a natural adhesive and covered with wood sourced from discarded materials in the furniture industry. The perforations in the wooden cladding facilitate the release and perception of the substrate's aroma. The registered trademark Teco® derives from the words tea and coffee, using their first syllables. Teco® panels are specifically designed for use in interior architecture and can be reintegrated into the biological cycle as compost. The panels are 300 x 300 x 12 mm in size. As a 100% biobased material, all components of Teco® originate from natural or renewable sources. The production of Teco® panels follows a clean and sustainable process, employing low-energy technologies and manual methods that align with the third-wave DIY approach. Furthermore, Teco® supports circular business models that promote the extended use of materials and products through practices such as reuse, remanufacturing, and repurposing. In doing so, Teco® contributes to environmental sustainability by minimizing waste and fostering a healthier, more sustainable future (Figure 6).

Conclusions

Biobased materials, such as the one developed in this study, present great potential for advancing environmental sustainability by reducing waste generation and decreasing reliance on non-renewable resources. Especially in the construction sector, one of the largest contributors to pollution, the integration of organic and industrial waste streams in material development not only minimizes environmental impact but also enhances the valorization of underutilized or discarded resources. This work highlights the capability of biobased materials to close production cycles in alignment with the principles of the circular economy, facilitating the reintegration of materials into natural and biological cycles. The Teco® panel, developed within the framework of a third-wave DIY methodology, demonstrates the feasibility of creating sustainable materials through the synergy of traditional craftsmanship, accessible technologies, and interdisciplinary expertise. The proposed process emphasizes the

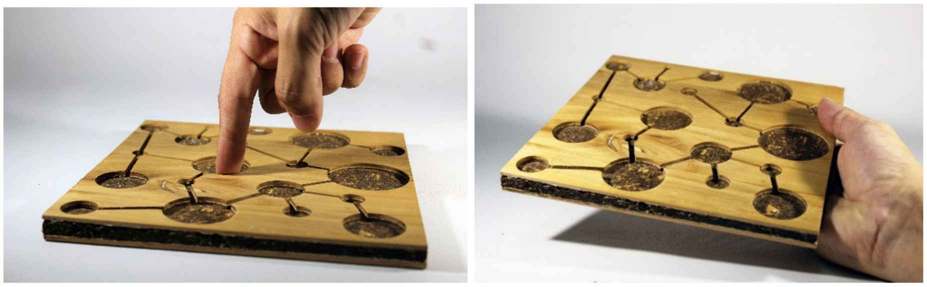

Figure 6. Teco ® final prototype dimensions 300 x 300 x12 mm.

advantages of leveraging local resources, employing rapid prototyping, and fostering experimentation as key strategies for innovation in material design. Additionally, the modular design and inherent compostability potential of the Teco® panel align closely with circular economy models, emphasizing its relevance in waste reduction and its contribution to a more sustainable and environmentally conscious future.

This study also validates the effectiveness of the third-wave DIY approach as a methodological framework for democratizing the development of advanced materials. By enabling communities to participate in the creation of localized, sustainable solutions, this approach supports the development of materials that reflect the identity of specific territories while addressing localized environmental challenges. Through the integration of waste materials and the application of low-tech, scalable solutions, this project establishes a replicable paradigm for addressing global issues related to waste management and sustainable material innovation. The research demonstrates that biobased materials have significant potential to mitigate the environmental impacts of construction, offering innovative alternatives that promote the use of local resources, close production cycles, and reduce waste, all in alignment with the principles of circular economy and sustainability.

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TECO®, UNA SOLUCIÓN DE MATERIAL BIOBASADO PARA LA ARQUITECTURA DE INTERIORES, QUE VALORIZA RESIDUOS DE CAFÉ, TÉ Y RETAZOS DE MADERA INDUSTRIAL

Jimena Alarcón Castro, Rosario Villegas Cabrera, Riccardo Balbo y Konstanza Navarro Ortíz

RESUMEN

La disminución de los recursos fósiles y el aumento de la contaminación debido a los materiales utilizados en la construcción tienen un impacto negativo en el medio ambiente. Para mitigar este impacto, el desarrollo de materiales basados en biomasa presenta una alternativa atractiva. El objetivo principal de esta investigación es diseñar un panel basado en biomasa incorporando Residuos Sólidos Municipales (RSM) y Residuos Sólidos Industriales (RSI) del sector madera, proporcionando una alternativa a los materiales de construcción tradicionales. La metodología consta de tres etapas: a) Identificación y selección de los RSM y RSI generados en Concepción, Chile; b) Desarrollo de un prototipo de material basado en biomasa; c) Propuesta de aplicaciones. El resultado es Teco®, un panel compuesto diseñado para ser utilizado como revestimiento en arquitectura interior, elaborado a partir de una mezcla de posos de café y residuos de té, cubierto con recortes de madera provenientes de la fabricación de muebles. Teco® tiene el potencial de reintegrarse al ciclo biológico como compost, promoviendo un ciclo continuo de la naturaleza a la naturaleza. Las conclusiones se centran en la validez del proceso DIY (hazlo tú mismo) para explorar alternativas que democratizan la ideación y fabricación de materiales basados en biomasa, priorizando el uso de residuos locales.

TECO®, UMA SOLUÇÃO DE MATERIAL BIOBASEADO PARA ARQUITETURA DE INTERIORES, VALORIZANDO RESÍDUOS DE CAFÉ, CHÁ E SOBRAS DE MADEIRA INDUSTRIAL

Jimena Alarcón Castro, Rosario Villegas Cabrera, Riccardo Balbo e Konstanza Navarro Ortíz

RESUMO

A depleção dos recursos fósseis e o aumento da poluição devido aos materiais utilizados na construção têm um impacto negativo no meio ambiente. Para mitigar esse impacto, o desenvolvimento de materiais à base de biomassa apresenta uma alternativa atraente. O principal objetivo desta pesquisa é projetar um painel à base de biomassa incorporando Resíduos Sólidos Municipais (RSM) e Resíduos Sólidos Industriais (RSI) do setor de madeira, oferecendo uma alternativa aos materiais de construção tradicionais. A metodologia consiste em três etapas: a) Identificação e seleção dos RSM e RSI gerados em Concepción, Chile; b) Desenvolvimento de um protótipo de material à base de biomassa; c) Proposta de aplicações. O resultado é o Teco®, um painel composto projetado para ser usado como revestimento em arquitetura de interiores, feito de uma mistura de borras de café e resíduos de chá, coberto com sobras de madeira provenientes da fabricação de móveis. O Teco® tem o potencial de ser reintegrado ao ciclo biológico como composto, promovendo um ciclo contínuo da natureza para a natureza. As conclusões focam na validade do processo DIY (faça você mesmo) para explorar alternativas que democratizem a ideação e fabricação de materiais à base de biomassa, priorizando o uso de resíduos locais.