The 30th

Annual International Conference of ISDRS on Sustainable Development Research

Linking Futures of Mountain and Ocean: Rescuing the SDGs 2030 for Sustainable Livelihood

PROCEEDINGS

June 10-14, 2024 | Kathmandu, Nepal

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Message from the Vice-Chancellor

With deep satisfaction and academic pride, I present this message as part of the proceedings of the 30th Annual Conference of the International Sustainable Development Research Society (ISDRS), successfully hosted in Kathmandu, Nepal from 10–14 June 2024.

Mid-West University was privileged to host this global event alongside Nepal Open University with Resources Himalaya Foundation as the secretariat, and esteemed national and international partners. The conference welcomed 300 participants from 47 countries, with 318 abstracts received from across five continents—making this event a truly global forum for sustainable development discourse.

Set against the stunning natural beauty of Nepal, the conference embraced the timely and powerful theme: "Linking Futures of Mountain and Ocean: Rescuing the SDGs 2030 for Sustainable Livelihood." This theme reflected Nepal's unique ecological and cultural context and emphasized the vital interconnections between mountain ecosystems and oceanic health, from glacial rivers to coastal livelihoods.

The eleven conference tracks spanned a wide spectrum—from biodiversity and climate resilience to sustainable cities and digital transformation. Each track fostered vibrant academic exchanges and practical reflections. These proceedings now encapsulate that rich body of knowledge and represent a milestone in our shared journey toward sustainability.

We extend our heartfelt thanks to the ISDRS community, the organizing committee, and every contributor. It is our sincere hope that these proceedings will continue to serve as a valuable resource for scholars, institutions, and change makers working to realize the promise of the SDGs—locally, regionally, and globally.

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Message

It is with immense pride and pleasure that I share this message in the proceedings of the 30th Annual International Conference of the International Sustainable Development Research Society (ISDRS), held in Kathmandu from 10–14 June 2024.

As a co-organizing institution, Nepal Open University was honored to play a vital role in convening this globally significant conference—one that brought together over 300 participants from 47 countries, with 318 abstracts submitted from more than 50 countries. This remarkable gathering of scholars, scientists, development professionals, and students truly reflected the multidisciplinary and international essence of ISDRS.

The theme of the conference—"Linking Futures of Mountain and Ocean: Rescuing the SDGs 2030 for Sustainable Livelihood"—deeply resonated with our national and institutional priorities. The dialogues underscored how sustainability is not merely a goal but a way of life—long practiced by indigenous communities. The rich discussions and collaborations explored sustainability from both natural and social science perspectives, bridging global aspirations with local realities.

Nepal's unique geography and cultural wealth provided an ideal backdrop for the diverse conference tracks—from climate change and energy to sustainability in the Himalayan region. These proceedings now serve as a lasting testament to that knowledge exchange and to the collective will to achieve the Sustainable Development Goals (SDGs) through research, innovation, and inclusive collaboration.

We are grateful to the ISDRS Secretariat, the organizing committee, and all contributing partners for their dedication. May this volume of proceedings continue to inspire scholarship, policy action, and global partnerships for a more sustainable future.

Professor Shilu Manandhar Bajracharya, PhD
Vice-Chancellor

Preface and Acknowledgements

The International Sustainable Development Research Society (ISDRS) held its 30th annual international conference in Kathmandu, the capital of the Himalayan nation of Nepal. The conference marked a significant milestone in advancing the global sustainability agenda. Hosted in a hybrid format, the conference brought together over 250 participants from 47 countries, representing one of the most extensive international gatherings in the post-COVID-19 "new normal."

The conference was inaugurated by the Vice President of Nepal, while the Deputy Prime Minister and the Minister for Foreign Affairs participated in the valedictory session, underscoring the national significance of the event.

Nepal's new universities Mid-West University and Nepal Open University jointly hosted the conference. They established an inclusive academic platform by engaging five recently founded universities from across the country: Agriculture and Forestry University, Far-Western University, Madhesh University, Purbanchal University, and Rajarshi Janak University. This collaborative initiative laid the groundwork for stronger inter-university cooperation across Nepal.

In addition to the universities, the conference was supported by 12 key institutions, including the University Grants Commission (Nepal), the National Trust for Nature Conservation (Nepal), UNDP, and UNESCO. Serving as the conference secretariat, the Resources Himalaya Foundation played a central role in coordinating logistics and mobilizing resources.

The conference featured 220 research contributions across 10 thematic tracks, showcasing the interconnected and multifaceted nature of sustainable development. It highlighted the critical need for inter- and transdisciplinary collaboration, localized strategies, and inclusive approaches. Of particular significance was the strong participation of scholars from the Global South and women researchers, whose contributions emphasized the importance of addressing context-specific sustainability challenges and solutions.

The event called for the strengthening of research cultures in emerging academic institutions, improved science communication, and deeper engagement with issues of equity and planetary boundaries. These themes are especially relevant for Nepal—a Least Developed Country facing severe climate vulnerability. Melting Himalayan glaciers, rising frequency of wildfires, and increasingly erratic weather patterns are threatening livelihoods, particularly in rural farming

communities. The timing of the conference was pivotal, as Nepal aspires to graduate to a developing nation status amidst these mounting sustainability challenges.

The conference served both as a challenge and an opportunity. It identified the urgent need to build robust platforms and mechanisms for collaboration among key actors in the Global South and emerging economies, reaffirming their crucial roles in achieving the Sustainable Development Goals (SDGs).

One of the key outcomes of the conference was the adoption of the Kathmandu Communiqué, which emphasized the importance of integrating the SDGs with planetary boundaries and understanding the socio-economic dimensions of sustainability—particularly equity, inclusivity, and the impacts of sustainability transitions on vulnerable populations.

We sincerely thank all partner organizations, volunteers, researchers, and scholars whose commitment and contributions were instrumental in making this conference a meaningful and memorable milestone in the global dialogue on sustainable development.

We extend special appreciation to the track reviewers, paper and poster presenters, and all participants, whose active engagement played a vital role in the conference's success.

Prof. Sjors Witjes, PhD
President
ISDRS 2024

Prof. Dinesh Bhuju, PhD
Convener
30th ISDRS Conference 2024 Kathmandu

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The Intersection between MDD and DIY Aimed at Promoting Growing Materials within Established Markets

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Abstract

The sustainable use of resources is a pressing challenge for our planet, demanding attention from product designers to foster a biocentric and sustainable future. Regenerative materials, such as Growing Materials (GM), are increasingly valued for their circularity and performance benefits. To enhance collaboration between designers and innovative materials, the Material Driven Design (MDD) methodology has been developed to identify suitable markets. In addition to this, emerging regenerative materials, adaptable to the Do It Yourself (DIY) approach, are gaining popularity beyond industry, enabling work with common tools without specialized skills. This contribution proposes integrating MDD with DIY to combine theoretical research with practical verification, with the objective to validate these materials and ensure their effective application in viable markets. The process involves four MDD steps and three experimental design phases, defined by the authors, to assess Bacterial Cellulose (BC) performance in upholstered furniture. Conclusions will highlight integration opportunities and analyze associated constraints, defining a new role for designers in the GMs landscape, extending from product realization to the design of related product systems.

Introduction

Within a landscape currently dominated by a climate crisis challenging the linear design and production mechanisms established since the Third Industrial Revolution (Jiang *et al.*, 2022), the concept of sustainability is evolving within product design. It now focuses on restoration, renewal, and revitalization of the societal relationship with the integrity of nature. Design has the potential to intervene to achieve these goals through the study of various design methodologies, each emphasizing different factors such as materials, forms, object use, production technologies, or end-of-life disposal programming.

The theorization and experimentation of new methodologies underscore the importance of Regenerative Design in transcending the creation of artifacts, buildings, or human well-being. Instead, it prioritizes researching and reconstructing interconnections between these elements and the ecosystems surrounding them, emphasizing the maintenance of well-being for all involved stakeholders (Blok, 2022).

Within this framework, as asserted by Wahl (2017) and numerous other researchers and theorists, one of the emerging possibilities for the design discipline to actively address the challenge of reducing resource demand and consumption is the use of regenerative materials, specifically biological and renewable ones (Wahl, 2017). This necessitates a shift towards integrated design and production relationships with natural processes, accelerating the intersection between biology and design (Myers and Antonelli, 2019). Indeed, over the past decade, designers have begun working with new materials utilizing natural growth processes and the reproduction of living organisms, following the concept of zero-state. This concept involves

designing to restore to ecosystems the same resources used in artifact creation, thereby guiding towards a positive impact on the planet (Jussila, 2023).

Following the possibilities of Regenerative Design, this research aims to identify new possibilities for design processes that not only integrate the use of regenerative materials but also assess their harmonies and dissonances with industrial production within established markets that currently have limitations in sustainability, such as upholstered furniture (EUROPUR, 2021). The dual objective of making object production more sustainable and directing it towards the use of regenerative materials requires a new methodology that enables designers to engage in conscientious design.

It is possible to observe how in the discipline of design there has long been a desire to enhance the value of materials, stemming from the need to shorten material innovation cycles within the market (Maine et aL, 2005). This has led to a design approach that places the materiality of the object at the center for reasons of performance, sustainability, and hedonism, thereby developing design methodologies that guide designers towards MDD, such as the methodology proposed by Karana *et al.* (2015). The motivations behind the development of these methodologies are consistent with the aim to promote the use of regenerative materials within large-scale design and production, fostering a paradigm shift towards biocentric design (Santos, 2021).

However, the specific design objectives of these emerging methodologies remain valid for materialfocused design but are still not aligned with the introduction of GMs within the discipline, as they are predominantly within the industrial landscape and therefore lack considerations dictated by the intrinsic living component of Living Materials (LMs).

Therefore, this contribution aims to investigate the possibilities offered by established design procedures within the world of industrial design to promote the integration of regenerative materials. In particular, it seeks to address two main questions following a critical analysis of selected methodologies and approaches that are consistent with the proposed regenerative scenario:

- What are the points of intersection between industrialization (typical of mass production) and regenerative materials? How can they be identified and enhanced to foster a dialogue between sustainability and efficiency?
- What opportunities does the designer have within a scenario that requires a more sustainable and regenerative approach to design and production?

To achieve this goal, an analysis of selected procedures is presented along with a theorization of their integration, followed by a testing phase where the resulting protocol was applied to design a product using GM, specifically BC. Specifically, the project aims to test this methodology for designing a product aligned with principles of Regenerative Design and Sustainable Design, utilizing only natural materials, minimizing resource use, and applying Sustainable Design strategies that include closed-loop systems in the end-of-life phase. The conclusions will critically analyze the design outcome, proposing new design and methodological possibilities for a regenerative scenario and responsible design.

Literature Review

Material Driven Design: The Methodology and Objectives

To achieve the presented objectives, the research has focused on analyzing design methodologies that emphasize the development and application of materials as a central point of design. Among these methodologies, the MDD has emerged over the past decade, developed by Karana *et al.* (2015), where material analysis serves as the focal point of design, and its limitations and possibilities guide the process to identify new scenarios (Karana *et al.*, 2015).

This methodology was developed to encourage material-focused design by valuing choices regarding materials not only for what they are but also for what they do (Manzini, 1989). The entire process thus focuses on a deep understanding of the material to capture its potential applications that enhance its mechanical, performance, or aesthetic qualities. Starting with the analysis of a specific material, it is crucial to understand its composition, possibilities, limitations, production processes, and the sensory experience it offers to users (Karana *et al.*, 2015).

By combining technical characterization of the material with its experiential characterization, this initial phase includes analyzing existing material applications, with observations on the resulting sensory experiences. This latter analysis is crucial for the methodology's objectives as it can facilitate easier market acceptance (Ashby and Johnson, 2010).

The goal of the first design step is therefore a comprehensive understanding of the material, followed by the designer's ability to systematize and reinterpret the collected data, including sensory, interpretive (meanings), affective (emotions), and performative (actions, performances) aspects(Giaccardi and Karana, 2015). This enables envisioning new application possibilities for the material or enhancing existing ones. The second design phase focuses on the designer's ability to imagine how a material can contribute to functional superiority (Karana *et al.*, 2015) when integrated into a product, thus creating a Vision that relates the material itself to other products, people, and contexts.

The purpose of the Material Experience Vision requires reflecting on the research conducted in the first phase to identify potential applications that do not force functionalities and performances inconsistent with the material properties. Studies involving users and benchmarking analysis are particularly relevant in this phase, as they help identify similar materials and their relationship with users (Karana *et al.*, 2015).

Following the definition of the Material Experience Vision, the designer is tasked with identifying plausible connections between the qualities of the material in question and the created vision. The third phase focuses on constructing how and when users interact with the material according to the designer's envisioned modes in creating the Vision, and thus how material experience patterns can manifest (Giaccardi and Karana, 2015). To achieve this goal, Karana *et al.* (2015, p. 44) proposes a brainstorming session where formal material properties are defined based on selected meanings that are considered explanatory of the relational pattern being referenced (Karana *et al.*, 2015). This approach allows evaluating the appeal of a similar material during benchmarking analysis to identify adjectives that best

describe the material under review and the ensuing characteristics that conceptually strengthen its sensory attributes.

In the fourth and final step, the designer initiates the concept generation phase by synthesizing data reprocessed from the previous three phases to design an object that enhances the material according to all considerations made during the preceding steps. This phase involves making-testing actions, as subsequent prototyping and product testing are anticipated but excluded from the MDD analysis and representation schema, as depicted in Figure 1. Given the aim to design with materials that are both fully developed and still in development, concept creation and the subsequent prototyping and testing phase depend on this variable.

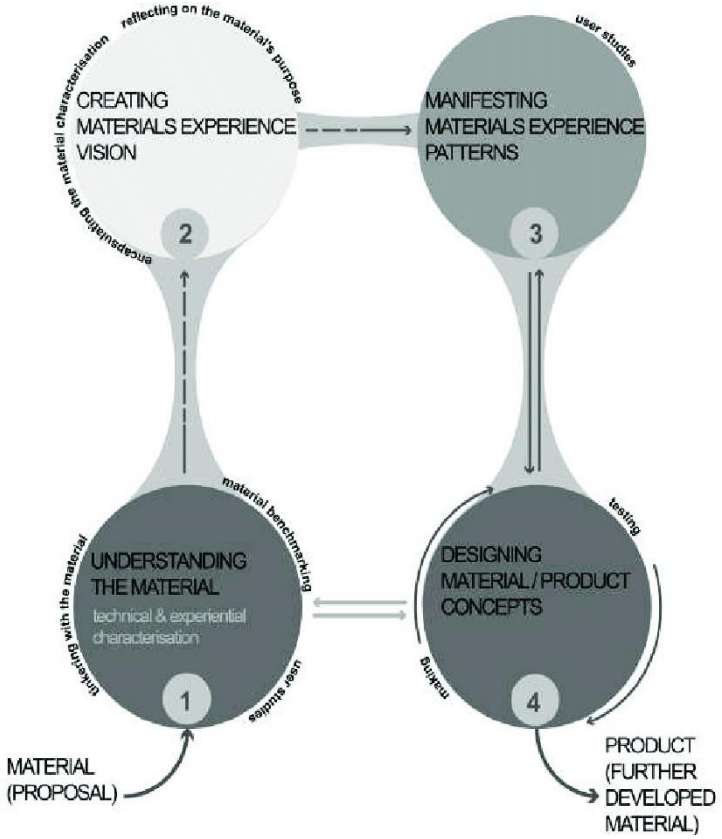

Figure 1. MDD method scheme, Karana *et al.*, 2015

The MDD methodology promotes a tangible engagement with materials, spanning from initial encounter to a comprehensive understanding of their complexities, aimed at expediting their integration into industrial production. This knowledge enables effective selection of sustainable design approaches to either slow down production cycles or close them (Bocken *et al.*, 2016), paving the way for a new ethical responsibility for designers.

The methodology schema defines specific steps allowing interaction with materials without making it obligatory. This offers designers the flexibility to choose operational levels based on the type of material, establishing a more or less tangible relationship with it. This expands the traditionally inherent possibilities of design disciplines, where material choice typically precedes object function. However, due to this dual approach, there are no vertically focused steps on tangible experimentation, crucial for processing GM. Furthermore, the intent to integrate materials into industrial processes via MDD does not fully align with the vital characterization distinguishing GM within the broader category of innovative materials, necessitating optimization of processes, re-evaluation of volumes, and production chain.

Therefore, there is a need to integrate innovative and variable processes, yet to be explored, requiring continuous practical experimentation alongside theoretical data collection, both subject to ongoing modification. For these reasons, MDD methodology proves highly intriguing for developing new scenarios where materials play a central role in responsible design, aiming for conscientious production considering the possibilities and limitations of the materials used, as well as their market influence. In the context of this research, it is essential to incorporate a segment focused on tangible experimentation to establish a new design process aimed at studying GM, respecting their intrinsic vitality and assessing scalability through critical analysis based on theoretical knowledge and practical evidence.

Do-It-Yourself: The Approach and Possibilities

Analyzing the methodological possibilities rooted in making, the DIY approach, also known as one-of, has been examined. This terminology has become popular as a fusion of craftsmanship and selfproduction (Rognoli *et al.*, 2015), driven by the desire to involve users in the design process and the demand for customization. Defined as an approach rather than a methodology due to the lack of a defined structure, the DIY approach refers to the general methods through which a particular methodology is implemented; in this case, it pertains to the inclination towards self-reliance and the availability of knowledge and means for self-management.

Initially associated with product customization, this approach is now contextualized within the realm of self-production thanks to the democratization of production technologies and the innovation spurred by open-source initiatives. Together, these developments have broadened the target audience within the making and design communities. Communities such as makers and activities in FabLabs have further solidified this product-oriented approach (Maffei and Bianchini, 2013) within large and medium-sized urban settings, supporting the circulation of ideas and the exchange of common interests, whether related to technologies, materials, or processes.

For these reasons, DIY is defined as a bottom-up approach as it encourages the democratization of material knowledge, experimentation opportunities, material processing based on learning by doing, and learning by interacting (Rognoli *et al.*, 2015).

These tangible experimental phases represent the missing element within the previously explored methodology, such as that of MDD, as well as an excellent opportunity for exploring innovative materials with constantly evolving vital components, such as GMs. This is because it focuses on direct

interaction with the material, thus including the possibility of altering results from various experiments, as well as analyzing variable parameters and equally diverse outcomes. This approach allows for a comprehensive understanding of the material not only by identifying its intrinsic possibilities but also by expanding observations to potential alterations, enabling exploration and understanding of these alterations.

To comprehend the real integration possibilities between the previously proposed methodology and the DIY approach, it is necessary to analyze the implications that the One-of world has on the field of design. Factors such as global idea exchange and local production and reproduction are closely related to industry (Gershenfeld, 2012).

In particular, the growth of the DIY culture creates an innovative scenario for the development of design processes with characteristics different from traditional ones, particularly in the close interaction between designers and production technologies. Specifically, in the case of LMs, there is a triple interaction among designers, new production technologies, and access to knowledge in the material/biological field (Maffei and Bianchini, 2013).

This sphere of action is of fundamental importance for designers, as it provides the opportunity to work with innovative regenerative materials, acquiring skills applicable within their discipline through a democratized approach that does not require specific expertise in different disciplines. This expands their own possibilities and develops integrated processes (Maffei and Bianchini, 2013).

It is also essential to understand the limitations associated with the isolated approach of DIY, primarily related to its artisanal origins. The One-of approach, when carried out independently and in isolation from other methodologies, assumes the role of a one-way exercise aimed at a single product or, as in the case of experimenting with innovative materials like GMs, a contribution to research. In the absence of a structured program, such as in the development and understanding of a new material, it would therefore be necessary to set a specific goal and establish a series of planned experiments to achieve it. This approach can lead to active participation in research but may miss the goal of contributing to reconciling design and project production with the development of regenerative materials.

Methodology

With the aim of defining a methodology that allows experimentation with GMs and encourages critical analysis of their introduction into the industrial market, we have integrated the MDD methodology, and the steps presented by Karana *et al.* (2015), along with the DIY approach as an orientation that democratizes experimentation. The possibilities envisaged by this dialogue include a crossdisciplinary design approach that incorporates tangible experiments and the acquisition of new skills, as well as critical and verified analysis of points of alignment between material innovation and the industrial world.

Compared to the schema previously presented in Figure 2, the process has been expanded by integrating three phases related to DIY experimentation: a phase of Cognitive Experimentation as termed by the authors, a second phase focused on Innovative Experimentation, and a third and final phase termed Enabling.

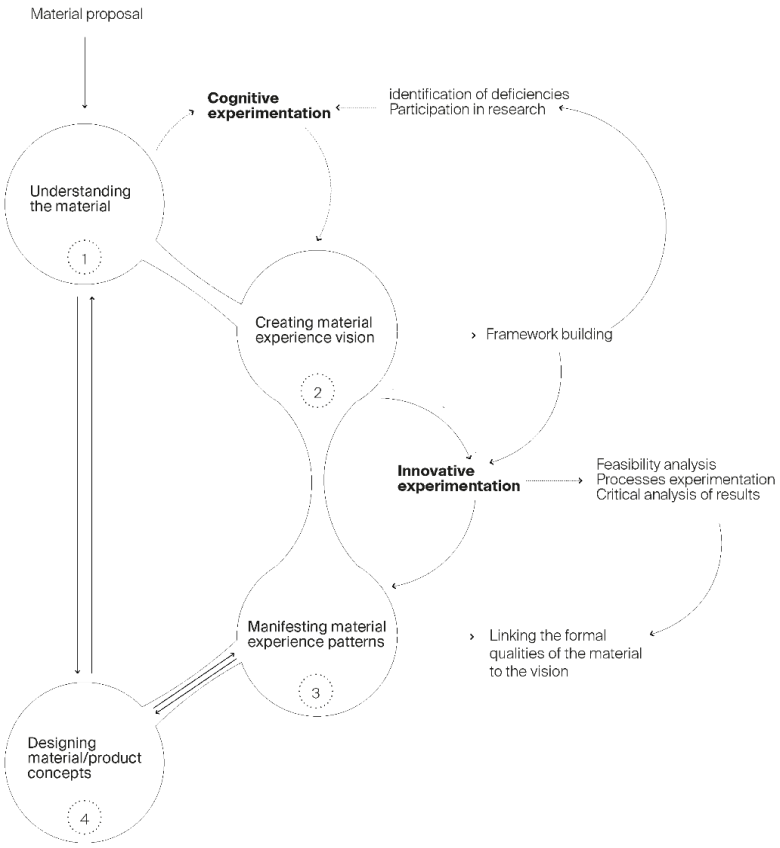

Figure 2. Methodology scheme presented by the authors

Cognitive Experimentation

The exploratory experimentation phase is positioned within the MDD framework between the material understanding and performance analysis, and the creation of a Material Experience Vision, which identifies potential applications consistent with the preliminary phase, i.e., verified material capabilities. Exploratory experimentation plays a role in deepening the understanding gained from the initial phase, guiding the designer to identify tangible material properties and verifiable observations. In the specific case of GM experimentation, the goal is to identify growth parameters that contribute to these performances, aiming to understand potential material modifications related to its vital components and ensuring their consistency.

The objective is thus to enter the envisioning phase with concrete and verified possibilities, facilitating the identification of new applications—a complex task given the innovation brought by regenerative materials, especially those whose performance varies with numerous parameters.

Furthermore, experimenting with the production processes of these materials involves developing a profound understanding and critical capacity to modify, redesign, and simplify these processes to alter their output.

The MDD phase dedicated to creating a Vision is thus facilitated not only by knowledge of the material but also by understanding the production process and its encompassed variables. Therefore, this step is bidirectionally correlated with exploratory experimentation because envisioning the potential of a material whose performance is easily modifiable implies the plausible need to alter the growth process and material output.

This possibility was observed during the application of the proposed methodology in this contribution to the design process involving BC, an LM produced from the fermentation of green tea and bacteria (Lee, 2011). In this case, exploratory experimentation involved evaluating optimal parameters to produce BC films within an acceptable fermentation time, with varying thicknesses to assess different mechanical performances. By testing the resistance of films with different thicknesses (Fig. 3), the ideal thickness for achieving films with good strength and acceptable production time was identified as 10 mm during extraction.

Figure 3. From the left: 4 mm thickness BC film, 7 mm thickness BC film, and 10 mm thickness BC film

The envisioning phase focused on enhancing the semi-structural properties by integrating the material into the upholstered furniture sector, subjecting it to tension. Given the aim to create a product demonstrating the ability to design not only with regenerative materials but also with conscious design principles using only natural materials and minimizing necessary resources, it was necessary to reorganize the exploratory experimentation phase. This phase was thus refocused on the possibility of reducing fermentation times, identifying parameters that allow minimizing resources required for optimized fermentation.

The exploratory experimentation phase was approached twice: first, to vertically understand the material, and second, to identify which parameters were modifiable to achieve results consistent with project goals. During both cycles, the methodology involved setting up experiments with materials suitable for production, daily monitoring of parameters, and at the end of the phase, systematizing and analyzing results to confirm or revise the envisioned outcomes.

Innovative Experimentation

The second phase of experimentation, termed 'innovative experimentation,' occurs following the creation of a material experience vision. This phase requires a project brief and objectives aligned with the verified capabilities of the material, as determined in both the initial MDD step and the exploratory experimentation phase. With the validation of achieving the objective using the analysed material, innovative experimentation aims to conduct a feasibility analysis of the created vision, experiment with production processes, and critically analyse the results.

While the exploratory experimentation phase verifies the material's capabilities, the innovative experimentation phase focuses on understanding the feasibility of the envisioned application. This involves analysing production processes and design requirements. This phase primarily concerns the designer's ability to leverage their design skills by developing the necessary tools and machinery and controlling different aspects of production (Bianchini, 2014). In the case of LMs, these skills must be applied to innovative production processes, evaluating their feasibility, optimization, and output.

Regarding the project involving BC applied to the upholstered furniture sector, it was necessary to determine which methodologies would enable coupling natural padding materials with BC—specifically in-situ coupling and ex-situ assembly—and identify the most suitable material for creating comfortable and high-performance padding comparable to expanded polyurethane. Following the selection of six natural-origin materials, both methodologies were tested for each material, and the results were compared. This analysis was conducted in terms of the product's aesthetic and mechanical quality, process optimization, and potential for industrialization. During this phase, experimentation involves producing samples that are tested using DIY methodology, which, while not empirically valid, allows for a qualitative and critical analysis of the hypothesized application possibilities.

Thus, we can assert that this phase involves an initial part of research and feasibility analysis, leading to the setup of experiments aimed at verifying both the hypothesized possibilities in the vision and critically analysing the obtained results. This helps identify the processes, materials, and key properties aligned with the specific design objectives. Given the close consequential relationship with the Envisioning phase and the third phase of the MDD, the step related to innovative experimentation has unidirectional exchanges with both mentioned project phases.

The phase dedicated to identifying the patterns through which material experiences manifest is enabled by the verifications on the feasibility of realizing the vision and the tangibility of the result in aesthetic and performance terms. This step leads to identifying one or more design possibilities dictated by the experience offered by the material in question, thus facilitating the subsequent phase of creating a product concept.

Enabling Experimentation

Within the MDD methodology, the concept generation phase involves manipulating components to obtain various material concepts, which subsequently lead to the final product concept, especially when starting from a material that is not fully developed (Karana *et al.*, 2015). With the proposed expansion in

this work, this possibility is extensively explored in the two previous experimental phases, arriving at the Concept Generation step with a clear schematic of the material's possibilities and limitations, as well as the explored domain. The creation of concepts within this new methodology, therefore, refers to finalizing the results obtained so far into an updated project idea relative to the previously constructed vision, ensuring coherence in both material and mechanical aspects throughout the experimental process.

In the case of designing with BC, the results previously obtained were systematized, analysing possibilities within the upholstered furniture scenario. The optimal type of furniture for demonstrating BC's application possibilities was identified, leading to its redesign following sustainable and circular strategies, such as Design for Disassembly and resource reduction.

Following the concept definition with considerations regarding its formal and functional aspects, an enabling experimentation phase was included. This phase focuses on designing technical and constructive details through reduced or full-scale prototyping. The goal of this phase is to test the constructive hypotheses derived from concept generation and definition, as well as the mechanical performances validated through non-empirical methodology in the innovative phase. It is structured into three stages: the first is dedicated to the project definition of the concept, including technical and material aspects; next is a phase for identifying suitable processes for prototyping and future production, concluding with a phase of testing regarding components, technical details, and targeted mechanical performances. These stages are essential for limiting the use of substantial resources required for full product prototyping to observe functional details.

Following the resolution of uncertainties regarding design and structural details, the experimentation phase leads to the creation of a prototype or the final product. This process involves resolving any issues, allowing for definitive testing.

While the prototyping and product development phase is part of the MDD framework, it is not considered critical within MDD because the methodology aims not only at identifying plausible innovative applications but also at participating in research related to new material development. However, given the different objectives of the research proposal in question, this phase becomes critically important. Specifically, in the case of designing with LMs, the purpose of the prototype is defined by Giaccardi (2019) as the desire to "support a process of reflection on the design activity and its outcome, what worked and what did not. In fulfilling this function, artifacts are used primarily in their evaluative capacity" (Giaccardi, 2019). Therefore, the prototyping phase is closely related to the previous enabling experimentation phase, including the possibility to reconsider and redesign the hypothesized production processes and conduct a second prototype for further evaluation. Prototyping can also lead the designer to reassess the proposed concept, resulting in redesigning processes, and so forth.

The iterative characteristic—continuously evolving through phases of proposals, testing, and modification occurring cyclically (Smith and Tjandra, 1998), influencing each other synergistically— of the design discussed here is of fundamental importance. This is due to the necessity of managing the application of an innovative material, its production process, and the design of the complete product. Furthermore, it is

essential to understand whether and how production processes are modified when transitioning from small-scale prototyping to full-scale implementation, associated with the general necessity in all projects to verify that the mechanical performance is suitable for the product type.

The creation of the second prototype thus concluded the design process, demonstrating the evidence obtained during each phase of the methodology, thereby summarizing them within a functional, verified product.

Results and Discussion

The methodology proposed here, applied to a design process—in this case, the creation of upholstered furniture with the integration of BC—allows for the verification of the effectiveness of the structured process. The objectives identified for each experimentation phase, as well as the correlations between these and the phases of the MDD framework, are compared with the results obtained for each phase of the design.

Examining the objectives set for the first experimentation phase, namely identifying gaps in research and literature regarding the knowledge and development of a GM, and active participation in the research, we can affirm that these are achieved through the bidirectionality established between creating a vision for application and the vertical knowledge phase of the material. This enables the identification and contextualization of different properties of the same material and subsequently altering the production process to achieve those specific, repeatable performances. In the case of designing with BC, identifying tensile strength, elasticity, and the sensory association with animal skin led to the possibility of using it as a semi-structural component in the upholstered furniture market. Following the phase dedicated to building a vision, which involved identifying application possibilities, it was also possible to set up ten experimentation cycles concerning the optimization of the fermentation cycle and minimizing resources useful for it, establishing a verified output as suitable and functional to the chosen sector and thus to the function associated with the material.

The second phase proposed as an integration of the methodology, innovative experimentation, instead sets objectives such as feasibility analysis and setting up and carrying out experiments related to the innovative production processes of the analysed material. To validate the feasibility of the vision and begin defining the first details such as production processes and materials, this phase requires the integration of the designer's skills with the literature related to GMs and already verified experiments. By doing so, it is possible to design and identify new production processes, new paired materials, and new structural possibilities. In the case of designing with BC, this phase allowed for identifying the suitable assembly method—such as ex situ assembly (Fig.4)—and the most performing material among the six selected for experimentation—such as natural latex foam. Following the validation of the feasibility of the vision concerning application possibilities and the identification of optimal methodologies for achieving a good quality product, it was possible to tackle the third phase of the MDD, which is related to the manifestation of the experiential patterns of materials. By analysing the reference type, i.e., the upholstery, and the obtained sample, a critical analysis was performed regarding the appeal of both.

Figure 4. On the left: Sample made of two layers of BC with cotton fibers padding, made with exsitu method; **On the right:** sample inserted in wood drum for the tensioning.

The results obtained and verified so far have laid the foundation for creating a structured concept, identifying an archetype within the target market—such as an upholstered stool—and designing it according to the previously established constraints. The design focused on adhering to Design for Disassembly principles, using wood for the entire structure and designing interlocking joints. Starting from the identification of the components forming the structure and their associated functions, the enabling experimentation phase led to the prototyping of the upholstery component at a 1:1 scale to verify how to scale and optimize the assembly process while achieving the same performance as the previously analysed scaled version. Additionally, resistance checks were performed on individual components, such as the end stops, where there were doubts related to mechanical performance. This entire phase resulted in the creation of a full-scale 1:1 prototype, on which necessary verifications were carried out regarding applied load stresses, joint resistance, assembly effectiveness, and the tensioning of the upholstery. These considerations necessarily led to formal and structural modifications, which were implemented through a re-evaluation of the concept's evolution, followed by another final prototyping phase.

Between the first and second prototyping, not only were the components modified to adhere to the previously identified design guidelines, but there were also changes in production processes—both concerning fermentation and CNC milling paths—to pursue the goal of optimizing time and resources necessary for production. For these reasons, the need to reevaluate the prototyping phase, which appeared marginal within the MDD framework, was confirmed. Additionally, it became clear that the three phases—concept design, enabling experimentation, and prototyping—needed to be correlated in a circular manner, highlighting the necessity for multiple verifications due to the introduction of an innovative material into established markets.

Conclusion

This contribution focuses on verifying the effectiveness of the proposed methodology through its application in designing products that integrate BC within an established market. This allowed us to examine how the research phases relate to the experimental ones, demonstrating new possibilities for designers in a landscape increasingly geared towards biocentric, regenerative, and sustainable design. The contribution aims to showcase the potential of a newly integrated methodology, which is why the section dedicated to methodology is more extensive compared to the subsequent considerations that serve

purely demonstrative purposes. The integration of theoretical research and tangible knowledge has provided a comprehensive overview of the material and its real-world applications.

Combining industrial design with innovative materials necessitates a re-evaluation of the concept of production time, which is currently linked to the cadence of industrial productivity. Integrating materials with inherent vital variables has revealed the limits imposed by these variables. Despite the potential for control and automation in the growth process, it remains subject to numerous non-parameterizable factors. This requires a reassessment of production time, aligning it with the regenerative timeline of materials to promote conscious resource use.

In pursuing the application of emerging materials within established markets, it will be crucial to consider their limitations and reevaluate production according to the regenerative principles applicable to all natural-origin materials, which, like GM materials, undergo a growth process.

Furthermore, attention must be given to the new possibilities for the designer's role within the evolving landscape of introducing new materials into the industrial scenario. The considerations outlined thus far address the initial question, asserting that the MDD approach, combined with the DIY methodology, can transform the designer's role and expand their possibilities and responsibilities. Through the intrinsic experimentation of the DIY approach, designers broaden their expertise in material biology, which, when integrated with methodical design skills and industrial production knowledge, opens up new design possibilities.

Initially, the adoption of a material-cantered design methodology within the broad field of LM experimentation, combined with a democratized approach that extends experimentation to the production process, results in the creation of artifacts that align with what Manzini (1990) described as 'the Third Way.' This approach allows the designer to adopt an intellectual attitude, participating actively in a broader research path beyond individual projects, not by providing precise, universally valid solutions, but by considering their product as a modest component of an open scenario, pursuing the constructive and critical role of design (Manzini, 1990).

Moreover, traditional industrial design involves understanding production processes to design coherent and feasible artifacts. In the proposed methodology, which focuses on the use of GM, the designer has the opportunity and necessity to design the entire production process suited to the product and the analyzed material, proactively contributing to the creation of a sustainable scenario.

Shifting the selection of materials from the final phase of design to the beginning of the process facilitates the development of plausible and coherent solutions for both the material and the market. This empowers the designer's role not only in designing objects but also in influencing social, economic, and environmental changes. The design process outlined and applied in the thesis aims to redefine collective social desires, habits, and values that have driven unsustainable practices so far (Williams and Collet, 2021), imagining alternatives to conventional production systems.

The multiple possibilities offered by adopting the proposed methodology in this contribution allow for future experimentation with materials different from GMs, validating other production possibilities and

new market sectors. This aligns with the interdisciplinary nature of the designer, dedicated to innovation not only in materials but also in form and function, and actively participating in responsible research and development.

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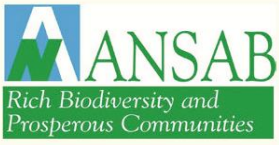
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