Transdisciplinary approach in biodesign: a case study of hybridization between design and scientific method in material design

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Abstract

Biodesign is an emerging disciplinary field that, in its multifaceted nature, finds in transdisciplinarity a promising pathway to address the complex challenges posed by contemporary scenarios. However, specific methodologies that connect the design mindset with the epistemological framework of scientific methods are still lacking. How can we grow the next generation of biodesigners in this scenario? Transdisciplinary dialogue provides a foundation for merging design thinking with scientific reasoning, leading to the development of methodologies and educational strategies aimed at creating shared languages and codes that promote synergy between design and science. This study presents the results of a methodological evolution—from multi and interdisciplinary approaches to transdisciplinary ones—through a workshop focused on material design, a course designed to train future biodesigners. This workshop engaged students in collaborative material tinkering activities, working side by side with scientists in an active laboratory setting. The study demonstrates that combining a material-driven design approach with scientific methodologies fosters iterative dialogical relationships, ultimately enriching and substantiating the final design outcomes.

Keywords: Biodesign, Material Tinkering, Transdisciplinary Approach, Design Methodology, Designer in Lab, Design and Science

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Introduction

The complexity of contemporary challenges—marked by environmental, social, political, and economic crises—demands a reorientation of design in terms of its challenges, approaches, methods, and tools (Lotti et al., 2022). In this context, as highlighted by various authors (Oxman, 2016) (Ito, 2016) (Lucibello, 2019) (Langella, 2019 & 2019a) (Mejía et al., 2023), the complexity of design responses must be nourished by heterogeneous and collaborative contributions from other disciplines. Accordingly, the design field must train professionals capable of understanding and interacting with other sciences in a more conscious and comprehensive manner to develop future application scenarios across all areas of design—from materials to products and systemic design—while addressing complex ethical issues. Based on this perspective, new approaches, methodologies, and tools are being developed to prepare professionals for transdisciplinary collaboration between design and science (Langella, 2019) (Marseglia, 2020) (Pollini, 2024). Biodesign, in particular, has emerged as the most advanced disciplinary field in this direction, focusing on the design of new materials and the exploration of novel manufacturing processes (Myers, 2012) (Ginsberg & Chieza, 2018). However, as noted by several authors (Camere & Karana, 2018) (Vijayakumar et al., 2024), these approaches, while innovative and potentially disruptive, lack clearly defined pedagogical and applied methods. As is widely acknowledged, the design field is marked by its particular way of knowing and is identified as the '*third area*' or '*third culture*' within the domain of education (Cross, 1982). What happens when the epistemologies of science intersect with those of design? What does it mean to combine two ways of knowing: science, which seeks to understand the nature of existing phenomena, and design, which aspires to invent valuable things that do not yet exist (Sydney A. Gregory in Cross, 1982 & 2006)? This article presents the results of an educational program where designer and scientists collaborated synergistically, sharing and redefining their practices in a blurred space between disciplinary boundaries, to create new mycocomposite materials. Materials remain a fundamental element of design, influencing the era in which we live (Ashby & Johnson, 2010). Their impact can be both positive, through their aesthetic and sensory qualities, and negative, in terms of waste generated across their entire lifecycle. For instance, in 2020, the mass of anthropogenic materials surpassed the total biomass of living organisms (Elhacham et al., 2020), highlighting how our ties with nature have been irreversibly severed (Antonelli & Tannir, 2019). In our time, it has become clear that human actions are deeply interwoven within the complexity of planetary systems (Morin, 2015). In this context, design carries a

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pivotal responsibility, as it not only shapes but also defines the material identity embedded in the products and systems it brings to life.

In recent years, designer have returned to focusing on materials—not merely as selectors, experimenters, or applicators, but as inventors and creators (Trebbi, 2024) of potential future material scenarios. This approach has been described by Rognoli et al. (2021a) as design for post-Anthropocene material transition. This paradigm shift has led many designers and researchers to focus on these aspects through various theories and practices, rooted in concepts such as *Material Activism* (Ribul, 2014), *Material Driven Design* (Karana, Barati et al., 2015), *Material Experience* (Karana et al., 2013, 2015, 2015a), *DIY Materials* (Rognoli et al., 2015; Velez et al., 2022), *Material Tinkering* (Parisi et al., 2017), and *Growing Design* (Camere & Karana, 2018).

Simultaneously, material design approaches involving collaborations between design and other sciences have been developed (Ferrara & Lucibello, 2009) (Langella, 2007, 2019 and 2019a) (Lucibello, 2019). In some of these theories and approaches, the collaboration between scientists and designer transcends individual disciplines, resulting in open, innovation-oriented partnerships. In this sense, as suggested by Ito (2016), the union of design and science can produce an approach that is both rigorous and flexible, enabling exploration, understanding, and contributions to science in an antidisciplinary way. In recent years, there has been a growing number of educational activities involving design students and professionals in material tinkering. These activities emphasize learning about materials through hands-on experiences to unlock opportunities from unconventional tools and processes while fostering creativity (Parisi et al., 2017). Notable examples include the *MaDe - Materials Designer* project (2019-2021), coordinated by Professor Valentina Rognoli, which aimed to demonstrate the impact material designers can have on the planet as agents of change for a responsibly designed future (Rognoli & Parisi, 2021). At the European and international levels, material and biodesign-oriented educational programs include the Master in Bio-Integrated Design (BIO-ID) at UCL (UK), the Biodesign Masterclass at TU Delft (NL), the Master in Global Innovation Design (GID) at the Royal College of Art (UK), the MA in Biodesign at Central Saint Martins (UK), and the Biodesign Challenge program, among others.

In alignment with this trend, the *Design for Sustainability Lab* at the DIDA Department (University of Florence) has, since 2021, offered a 3-credit educational program—the

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Material beyond Materials (MbM) *workshop*—as part of the Bachelor's degree in *Product, Interior, Communication, and Eco-Social Design*.

In its third edition (2023-2024), the *MbM* workshop is rooted in concepts of sustainability and regeneration. It aims to engage students in exploring the relationship between the circular economy and material tinkering through the hybrid tools of biodesign. Each student is required to select a waste material or byproduct from local supply chains as a starting point for material experimentation. Guided by a systemic design approach oriented toward the circular economy (Bistagnino, 2009), these material experiments and potential applications must be ecologically sustainable and have minimal environmental impact. Participants are also asked to reflect deeply on the concept of "*material flow*" and the systemic implications of their design choices. The workshop aims to train the first generation of material-focused biodesigners at the University of Florence (UNIFI), introducing them to the principles of material design and biodesign. Given the workshop's highly heterogeneous content, its three editions required a methodological evolution toward a more inclusive approach that integrates other disciplines, fostering dialogue with the sciences to develop knowledge and skills beyond traditional design fields.

In this sense, *MbM III* has evolved into what can be described as *Transdisciplinary Material BioTinkering* (TMBT) *method,* a design method for the design and development of biofabricated materials in educational contexts, supporting the training of future biodesigners. Here, the student-designer not only acquires basic biological knowledge but also collaborates side by side with scientists—from concept development to laboratory experimentation—acting as a true *Designer in Lab* (Langella in Pollini, 2021) (Pollini, 2024).

Methods

The *MbM Workshop* is grounded in the principles of *Material Experience* (Karana, Pedgley & Rognoli, 2013) and *Material-Driven Design* (MDD), as outlined by Karana et al. (2015), this approach facilitates the design of material experiences starting from the material itself. The first edition of the *MbM Workshop* integrated the *MDD* approach and involved students in three specific steps: *Explore Materials* - activities in this step focused on data extraction, understanding the properties and constraints of the selected materials, and identifying their potential. During this stage, students engaged in exploratory research through tinkering and online research to develop awareness about the chosen material; *Roll Up Your Sleeves* - this

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step involved students experimenting with DIY processes and techniques to develop the material. It was characterized by "borrowing" knowledge from other disciplines, such as biology, fostering processes of cross-pollination; *Annotate* - in this step, students were required to provide both technical and aesthetic-sensory characterizations of the material samples they produced using precompiled forms. At the end of the workshop, student feedback was collected informally and through direct observation; the information was used to shape the methodological framework for the second edition.

The second edition of *MbM* retained the foundational methodology described above. However, considering the themes of sustainability and circularity, it was deemed necessary to further integrate contributions from other scientific fields, particularly involving experts from biology, materials science, and wood technology. This aimed to support students in acquiring technical knowledge to deepen their understanding of materials. Like the first edition, this iteration concluded with a final survey (Appendix 1) of the participants, and the results were used to inform the methodology of the third edition.

The third edition of *MbM*, named the *Biodesign Edition*, aimed to define a simultaneous material design methodology across multiple disciplines. *MbM III* focused on biofabrication techniques characterized by scientific approaches and technological complexity, which require specific and detailed knowledge for optimal application. The workshop revolved around the use of fungal mycelium - *Pleurotus ostreatus* -, tested with various types of local industrial by-products and waste streams—such as those from the textile, paper, and agro-industrial sectors—, with the goal of obtaining circular material samples alongside related application concepts. Given the peculiar methodology adopted, the workshop required collaboration with living organisms - '*nature as a co-worker*' (Collet, 2013 & 2021) (Roudavsky, 20219 8Lucibello & Montalti, 2019) or '*nature as co-designer*' (Camere and Karana, 2018)—, thereby necessitating a more advanced technical-scientific level compared to a typical DIY approach. This entailed an enhancement of scientific knowledge from the outset, introducing concepts such as general biology, the scientific method, and laboratory best practices - *Bio Safety Level 1 Lab* -, in order to establish a solid foundation for achieving appropriate theoretical and practical results aligned with the increased technological scope. For these reasons, the involvement of other scientific disciplines was extended across all phases of teaching and coaching, with the objective of creating moments of collaboration at the intersections of individual disciplines. Similarly, the *MDD* method was evolved into a more complex and iterative structure to effectively address the scientific and experimental needs of the highly transdisciplinary application field.

In this context, the approach of the third edition of *MbM* can be described as a *transdisciplinary biotinkering* process, where designer and scientists collaborated across design methodology and scientific methodology (Cross et al., 1981) throughout all phases of the design process. This workshop also concluded with a survey where students had the opportunity to share their opinions (Appendix 1).

The proposed method emerged from a series of workshops, which enabled the research team to develop an approach that could potentially be replicated by other researchers. While the method itself is reproducible, the outcomes—like in any design project—will naturally vary depending on the participants and the subject of the study. The TMBT method we present can serve as a foundation for other researchers looking to transdicplinary biodesign workshops or other educational experiences within the field of biodesign.

Transdisciplinary Material BioTinkering (TMBT) Method

Based on the theoretical and methodological foundations introduced in this article, methods and tools have been developed to integrate transdisciplinary approaches for the creation of *biofabricated materials* (Poblete et al., 2024). These were tested during the third edition of the *Material beyond Materials workshop*, where aspiring biodesigners created fungal mycelium (*P. ostreatus*)-based material samples.

Figure 1 illustrates the "*Transdisciplinary Material BioTinkering* (TMBT)" *method*, which consists of six main steps: 1) *Understanding Material*; 2) *Material Experience Vision*; 3) *Material Lab Experiment Design*; 4) *Lab Experiment*; 5) *Concept Design* (simultaneous with Step 2); 6) *Samples Production*. The steps and activities of the TMBT method are briefly explained below.

TMBT Method. Step 1 - Into Material

In Step 1, the aspiring biodesigners is encouraged to deepen their knowledge across various disciplinary fields to achieve a more comprehensive and cross-cutting understanding of the potential applications and properties of the material. This phase emphasizes synthesizing acquired knowledge to guide the student towards an informed selection of raw materials, application methods, and an initial transdisciplinary discussion. Step 1 consists of four consecutive activities:

To Know In this activity, students participated in lectures on, Etichs and Design for Sustainability, Material Design, Biology, and Agriculture. Material Design lectures focused on circular economy and biodesign, emphasizing biofabrication and material tinkering. The interdisciplinary topics in Biology included the fundamentals of cell theory, the metabolism of living organisms, energy transfer, biodiversity, and ecosystem interactions. Furthermore, in preparation for the experimental phases – *Designer in Lab* –, the scientific method and best practices within the biological laboratory were introduced. Finally, in relation to the workshop theme, the study of fungal biology and ecology was explored in depth, with a focus on the most innovative techniques for their cultivation. This activity aimed to provide the student with all the necessary knowledge for the creation of the final sample, going beyond a merely technical-sensory approach fostering a systemic and ecological understanding of the material and living matter. By doing so, students explored raw materials, collaborating organisms (Collet, 2013 & 2021), and the final product from a more conscious and integrated perspective (Cantini, 2024). The goal of these initial concepts is to help students understand all four dimensions of transdisciplinarity as proposed by Max-Neef (2005): disciplines such as Biology and Agriculture for the empirical dimension, Material Design for the pragmatic dimension, Design for Sustainability for both the pragmatic and normative dimensions, and Ethics for the value-based dimension.

To Understand In this activity, characterized by a field analysis, students explored fungal mycelium cultivation techniques by visiting a local company and a Biosafety Level 1 laboratory under the guidance of experts. The objective was to connect the technical knowledge acquired during the "*To Know*" activity with hands-on practices of the cooperating organism, highlighting the crafting properties as well as the technical and technological limitations of current cultivation practices (Camere & Karana, 2018). Additionally, substrate preparation practices for biofabrication were introduced. Should any uncertainties arise regarding the properties, cultivation, manipulation, ecology, or aspects related to the organism, a return to the theoretical phase is planned for further investigation.

To Think During this activity, aspiring biodesigners collaborated with researchers from various disciplines to generate preliminary ideas for new biofabricated materials. Using a transdisciplinary brainstorming approach inspired by De Bono's method (2015), students explored potential starting by-products, application scenarios, shapes, final outputs, and possible technical-sensory properties. Finally, each student received a *biodesign agenda*, a

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hybrid design tool, whose objectives and usage were detailed. In the subsequent phases, this tool aimed to generate potential design ideas through individual and collective contributions, fostering convergence and synergy among the proposals. In this brainstorming phase, students and expert scientists were able to dialogue in a transdisciplinary way about the first project ideas, encouraging cross-stimulation of creativity. Finally, on the *biodesign agenda*, students and experts involved simultaneously designed the experiment to be carried out in the laboratory.

To Select Students selected a substrate for fungal-based material development, exploring its properties, constraints, and potential through tinkering activities. The selection process followed a systemic approach aligned with circular economy principles, utilizing by-products from local supply chains (e.g., textile, paper, agro-industrial), by following the knowledge acquired in “*To Know*” and “*To Understand*” activities. This step allowed students to select a waste by-product, addressing the Ethical dimension required by the transdisciplinary approach (Max-Neef, 2005). In some cases, students engaged directly with the supply chains providing the by-products. Students then began substrate preparation, applying best practices learned earlier. This activity deepened their understanding of the chosen waste materials and prepared them for the material concept design and experiment planning phases; it aims to create connections between substrates, collaborating organisms, and hypotheses of the final outcome. Additionally, substrate preparation and sterilization activities can negatively affect the characteristics of the substrate. In such cases, a return to the “*To Think*” phase is planned to help the student select more stable alternatives.

TMBT Method. Step 2 - Material Experience Vision Step 2, defined by the activity “*To View*”, invites the designer to reflect on the future purpose of the material, defining its vision and the desired technical and aesthetic-sensory characteristics for the final material-product. In order to communicate with experts from other disciplines, the student is free to use any method: writing, moodboards, sketches, documenting everything in the *biodesign agenda*. In this phase, students and other experts involved interacted directly through the *biodesign agenda (Appendix 2)*, principally using sketching as a shared language.

TMBT Method. Step 3 - Material Lab Experiment Design In Step 3, characterized by the activity “*To Design Micro*”, the future biodesigners is encouraged to design, using the *biodesign agenda*, an experiment on the biofabrication of a material to be carried out in the laboratory. The most interesting characteristics emerging from Step 2 - *Material Experience*

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Vision - are broken down into individual questions, from which hypotheses are developed to be tested. These hypotheses lead to the creation of individual experiments to be conducted in Step 4 - *Lab Experiment* -. At this stage, the student, supported by experts from other disciplines, actively participates in the theoretical construction of the experiment. Specifically, the participant is asked to design, using the *biodesign agenda* - *Science Sketches* (Langella in Pollini, 2021) - the experiment for a controlled cultivation space, common in biological fields, namely a 90mm Petri dish. This step aims to stimulate the student to actively engage in the preparation of a scientific experiment, attempting to train the future biodesigners in the ways of thinking used in other sciences. The participant is encouraged to apply their design skills in a scientific environment. At the end of this step, the students, with the prepared substrate and the experiment designed and documented in the *biodesign agenda*, enter the laboratory for the testing phase - "*To Test*".

This phase of the method is where the various disciplines involved collaborate most closely, transcending disciplinary boundaries. The designer, thanks to the scientific knowledge acquired in the previous phases, is able to engage with the other disciplines in a more scientific manner. On the other hand, the scientist is creatively stimulated through the biodesign agenda, in which the student not only develops sketches and design hypotheses but also envisions, starting from the microscale, the potential growth of the material. Design students, design teachers, mushroom cultivation experts, and biologists collaborated directly on the *biodesign agenda*, thus using it as a tool for transdiciplinary dialogue.

TMBT Method Step 4 - Lab Experiment In Step 4, defined by the activity "*To Test*", the student begins to experiment within a laboratory (Langella, 2019) (Sawa, 2016) (Pollini, 2024) through *transdisciplinary biotinkering* activities. In this step, the designer assumes the role of *Designer in Lab* (Langella in Pollini, 2021) (Pollini, 2024). Using laboratory materials and tools, and under the guidance of an expert (e.g., biologist), the student applies the knowledge gained, confronting the practical challenges that underlie this type of experience. All experiences and data that emerge during this phase are recorded and documented in the Biodesign Agenda, which is used here as a laboratory notebook. After the laboratory experience, students monitor the temporal evolution of the experiments at defined intervals, noting every variable. Four possible outcomes are anticipated from this step, all depending on the results obtained and recorded in the *biodesign agenda*:

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- *Consistent data with the hypotheses* (black arrows, Figure.1) - If the experiential knowledge process of the material is deemed complete, proceed to Step 6. - If the experiential knowledge process of the material is not complete, return to Step 2, by formulating new hypotheses and starting a new experimental cycle.
- *Inconsistent data with the hypotheses* (orange arrow, Figure.1)
  - We expect to be able to return to Step 2 to revise the hypotheses and design a new experiment

- *Contradictory Data or Procedural Errors* (orange arrow, Figure.1) We expect to be able to return Step 3 to redesign or repeat the experiment.

TMBT Method. Step 5 - Designing Scenario In this step, defined by the activity "*To Imagine*", the student is asked to design potential concepts and application scenarios for the biofabricated material, using design-specific methods and tools in collaboration with other expert involved. The *TMBT* method emphasizes a strong influence of laboratory test data on scenario design. This influence is not strictly sequential but can occur at any point between Steps 2 and 6 (time range of influence shown in the grey area of Fig.1).

TMBT Method. Step 6 - Samples Production In this step, characterized by the activity "*To Collect*", the student proceeds with the realization of the material. In collaboration with experts from other disciplines, the student is encouraged to select the experiments that show the most consistent and promising data. Using a DIY approach, the participants assess how to improve the structural properties of the samples, advancing towards the creation of a new material. Once again, the use of the *biodesign agenda* is crucial, as it will contain all the formulations and notes necessary to repeat and refine any new tests.

Results

Approximately 70 students from the Bachelor's *Degree program in Product, Communication, Interior, and Eco-Social Design* (UNIFI) participated in the three editions of the *MbM workshop*.

First Edition The first edition of *MbM* enabled students to complete their coursework by creating a material/semi-finished product based on circular economy principles, empirically experimenting with their ideas and producing DIY material samples (Rognoli et al., 2015), along with their respective physical and sensory characterizations. During this initial edition, references to other sciences—such as biology and materials science—were merely "borrowed," with no direct contributions from experts in these fields. Students adopted a purely DIY approach, relying primarily on case studies and online databases related to DIY materials. On this basis, the first edition’s approach can be classified as multidisciplinary or pluridisciplinary (Max-Neef, 2005) (Moreno & Villalba, 2018). That is, design leveraged knowledge previously developed in other disciplines, attempting to integrate it into the design of new materials without specific coordination among the disciplines involved. In this context, while the design approach shared numerous perspectives with other fields of knowledge, its aim was to borrow references from other disciplines without losing its distinctive creative and experimental nature, which was oriented toward achieving practical solutions. At the end of the workshop, feedback from students was collected informally through a classroom work session and direct observation. The results of the final feedback proposed to participants showed a general satisfaction with the students' experience, especially regarding the exploratory phase and the material tinkering process. However, the informal feedback also highlighted some critical issues, including: the limited basic knowledge of materials design by students (due to the absence of contributions from other disciplines and methodologies), the lack of a laboratory and the necessary tools for material modification and, finally, the poor knowledge of biological materials and processes - such as fungi, algae and bacteria - especially regarding their functional and microscopic aspects (due to the lack of adequate equipment). The workshop program ended with a final exhibition at the Design Campus (University of Florence), where all the projects were displayed (Figure 2).

Second Edition The second edition of *MbM* enhanced the "*Explore Materials*" and "*Roll Up Your Sleeves*" steps from the first edition by incorporating contributions from other disciplines, particularly biology, chemistry, and materials science, to address some of the shortcomings identified during the initial workshop. Specifically, a biology researcher, a professor specializing in wood technology, a professor of materials engineering, and four design researchers[1] affiliated with the *Design4Materials Network* (Carullo et al., 2017) contributed their expertise. These experts introduced approaches to materials design that bridged design and other sciences. The aim was to provide students with technical knowledge to deepen their understanding of materials. Contributions from these disciplines sought to broaden students’ perspectives and scenarios, encouraging them to rethink both the types of

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waste materials selected for experimentation and the transformation processes, along with the potential applications of the new materials. The interactions between participants and experts also aimed to stimulate reflection on "*material flow*" and the potential ecological impact of their experiments. These contributions enriched the coaching activities as well; by engaging in reflections and discussions across different disciplines, it was possible to provide support during tinkering activities by offering technical knowledge related to material manipulation. Thus, the second workshop edition can be described as interdisciplinary (Moreno & Villalba, 2018), meaning that the interactions between the involved disciplines involved sharing experiences, methods, tools, and models. The results obtained, compared to the previous edition, were more coherent and integrated, addressing complex real-world problems related to the circular economy. The interdisciplinarity in the second workshop was therefore intentional or pragmatic (Max-Neef, 2005), meaning that it connected disciplines at the pragmatic level - Design - with disciplines at the empirical level. According to Max-Neef's theory, design thus became interdisciplinary, providing a defined purpose to the empirical field represented by biology and materials science through the project. However, despite this approach, students were unable to fully grasp certain aspects of materials, particularly at the microscopic scale and in terms of laboratory material manipulation. The creation of samples still followed an exclusively DIY approach, as in the first edition. Furthermore, the experimental design process was not fully optimized, lacking the necessary connection between design thinking and scientific methodology to ensure that project outcomes were evaluable, replicable, and self-correcting. The second workshop concluded with the exhibition *UP TO THE CRAFT - Generative Paths* - at the *International Handicrafts Trade Fair in Florence*, organized by *OMA (Osservatorio Mestieri d'Arte)* (Figure 3). The survey conducted at the end of this edition highlighted the significant impact of contributions from other disciplines. Many students expressed satisfaction in interacting with experts from other fields, especially regarding the support they provided in the technical and practical choices made for the sample designs and the microscopic understanding of material properties, including their chemical and physical characteristics. At the same time, the survey revealed persistent challenges, such as limited foundational knowledge, inadequate tools and facilities, and - among some students - a need for greater proficiency in biology and laboratory practices (Appendix 1 for further details).

Third Edition, TMBT method definition In the third edition of *MbM*, named the *Biodesign edition*, students collaborated throughout all stages of the design process with a

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biologist and an agronomist-entrepreneur[2] experienced in cultivation of fungi at all stages of the design process (Figure 4). The methodological structure introduced in the previous section (*Transdisciplinary Material BioTinkering*, or *TMBT*) represents an evolution of the approaches adopted in the first two workshops. It enabled the research group to address the scientific and experimental demands of an approach integrating design and scientific disciplines. As is often the case in transdisciplinary collaborations, specific tools for interaction between participants were created progressively (Moreno & Villalba, 2018). The *TMBT* method described in the earlier section was not clearly predefined but rather evolved alongside the project itself. In other words, the practical development nurtured the theoretical framework, and vice versa, in a dialogic process oriented toward discovering and defining a shared space between the involved disciplines. In this sense, the methodological definition can be considered an instance of *Research Through Design* (RtD) (Frayling, 1993) (Zimmerman, 2010) (Pollini, 2024), combining design practices with scientific inquiry. As Cross (1982) notes, the invention of the method preceded the theoretical understanding: action came before methodological comprehension. According to Varela & Shear (1999), through reflection, cognitive approaches, and practical experience, subjective practices can transform into a structured body of knowledge, as occurred in the development of *TMBT*. *TMBT* combines a traditional design method (Bonsiepe, 1993) - characterized by the reflective analysis and understanding of the problem, the creative design phase of concept definition and development, and the project realization phase - with the *MDD* (*Material Driven Design*) approach, which focuses on experiential and direct material research to produce physical samples. It also integrates the scientific method, whose steps include: formulating a hypothesis, designing and conducting experiments, collecting and analyzing data, and interpreting results. In a way, *TMBT* bridges the "*ways of knowing*" of science and design (Cross et al., 1982) to establish a methodological framework for transdisciplinary approaches in the biodesign context, aimed at designing new materials. This methodology does not dilute the distinct cognitive processes of design but instead enriches them with a scientific dimension essential for tackling the complexities of contemporary challenges. As a result, students were able to achieve outcomes that were not only more intricate and reliable but also easier to validate and replicate. This was made possible by the experimental design process and the *biodesign agenda*, which served both as a project management tool and as a laboratory notebook. By building on a traditional design process, *TMBT* respects the discipline's "*ways of knowing*" (Cross, 1982, 2006) while expanding and harmonizing them toward a transdisciplinary dimension. Designer, as Cross (1982) explains, typically aim to

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find a workable solution—not necessarily the best one—among many possible alternatives. In *TMBT*, a brainstorming session involving all disciplines occurs in the *Into Material* step to identify a range of potential solutions. One of these solutions is then developed during the *Concept Design* and *Material Experience Vision* steps, progressing to experimental design and laboratory implementation, and culminating in collecting final samples. While *TMBT* retains the designer's rapid solution-finding approach, it also allows for exploration of multiple alternatives if the initial solution does not meet the design intentions. Steps such as *Material Experience Vision*, *Material Lab Experiment Design*, and *Lab Experiment*, along with the overarching *Concept Design*, incorporate recursive processes similar to the scientific method. These steps rely on inductive and deductive insights, supplemented by the abductive reasoning typical of designer. Thus, with *TMBT*, a possible solution is quickly identified; the difference compared to a traditional design process lies in the ability to investigate a number of possible solutions if the first one does not align with the design intentions. Indeed, steps 2 - *Material Experience Vision* -, 3 - *Material Lab Experiment Design* -, and 4 - *Lab Experiment* -, and in a transversal way step 5 - *Concept Design* -, in analogy with the scientific method, are recursive and based on inductive-deductive intuitions but fueled by the abductive thinking process typical of designers. In these four stages, the use of the *biodesign agenda* was essential, as students took notes, described the material, designed the material and the experiment—from the micro scale to sensory aspects—along with the conceptualization of possible applications (Figure 5). The solution-oriented approach described by Cross (1982) is closely linked to the type of problems that designers typically face, namely *Wicked Problems* (Buchanan, 1992). In this sense, the ways of knowing of designer can only be constructive; that is, unlike science, which seeks solutions in an analytical way, focusing on how things are, designers are interested in how things should be (Simon, 1988). In the proposed method, indeed, in the iterative steps between *Material Experience Vision* and *Lab Experiment*, students, using sketches as a communication method with scientists (Langella, 2019) (Langella in Pollini, 2021) - sketches of the material, the experiment, and the potential design application - tried to establish the foundations of the design concept in order to define the design problem and offer an immediate possible solution. On the other hand, scientists sought solutions with an inductive-deductive approach, side by side with the designers, to reach the conceptualized design hypothesis. Conversely, scientists adopted an inductive-deductive approach, working closely with designers to refine the initially conceptualized design hypothesis. During these dialogues between science and design in the third workshop, another "*way of knowing*"

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theorized by Cross (1982) was emphasized: the use of codes - sketches and the integration of heterogeneous domains -. These codes allowed designers to translate abstract concepts - such as Material *Experience Vision*, *Concept Design*, and *Material Lab Experiment Design* - into concrete solutions during the *Lab Experiment* and *Sample Production* steps. In particular, in the *Material Lab Experiment Design* step, students undertook a novel activity for designers: planning scientific experiments. However, they still applied the codes typical of design disciplines—sketches, and the ability to synthesize heterogeneous domains—to effectively communicate with the other sciences. During the *Concept Design* step, in addition to leveraging the "*way of knowing*" through sketches, designers also applied their ability to interpret and rewrite material culture. As Cross (1982) notes, objects carry vast knowledge through their forms, functions, and materials. Immersed in material culture, designers are uniquely equipped to interpret and recontextualize this knowledge into new objects. This "*way of knowing*" was particularly evident in the *Concept Design* step, where students proposed potential applications for the developed material solutions. Using sketches, designers demonstrated the feasibility of their ideas to scientists, fostering a more grounded and expansive dialogue. In the *Lab Experiment* step (Figure 6), students, having acquired prior knowledge, wore lab coats and entered a self-constructed laboratory equivalent to a Biosafety Level I Lab. They worked hands-on to produce material samples under the supervision of biologists and agronomists specializing in mycology (*Designer in Lab*, Pollini, 2024) (Langella in Pollini, 2021). Even in the laboratory, the *biodesign agenda* proved indispensable—not only as a tool for dialogue across disciplines but also as a means of constructing a shared process. Scientists actively collaborated, using sketches to contribute to the workflow. Based on this experience, we can conclude that designer, as Pollini (2024) argue, initially hesitant about the scientific approach and laboratory methods, achieved more complex results than in previous editions through continuous transdisciplinary engagement and the acquisition of new knowledge.

The outcomes reveal that the third edition of *MbM* employed a *transdisciplinary biotinkering approach*, fostering collaboration between designer and scientists across design and scientific methods throughout all process phases. This methodology engaged all hierarchical levels proposed by Max-Neef (2005). In fact, during the workshop, empirical disciplines – biology, agriculture, and materials science – were made to interact, allowing us to understand '*what exists*'; pragmatic and normative disciplines – such as architecture and design – helped answer '*what are we capable of doing?*' (with what we have learned from the

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empirical level), and '*what do we want to do*?'. Finally, disciplines related to value and ethics – now incorporated into the design for sustainability field – posed the question '*what should we do?*' or rather '*how should we do what we want to do?*'. According to Max-Neef (2005), any multiple relationship that includes all four of the levels described above defines a transdisciplinary action.

The final survey, submitted to the future biodesigners, highlights meaningful insights and areas for further reflection. In general, the simultaneous contribution of the different disciplines was positively evaluated by all students, especially in the laboratory phases. Instead, among the main difficulties that emerged were the laboratory practice and the difficult understanding of the organism and consequently the difficulty in generating ideas related to it. However, these difficulties, as highlighted by some students, were overcome thanks to the collaboration between the different expertise involved. Another important piece of data that emerged from the survey, which reinforces the theme of transdisciplinarity, was the direct contact with an external company expert in mushroom cultivation (Appendix 1 for further details).

The third workshop concluded with students presenting their work at *Milano Design Week 2024* as part of the exhibition "*Design Across the Borders in Times of Global Crisis*", organized by the *Design for Sustainability Lab* at *BASE Milano/We Will Design*. Additionally, the results of *MbM III* were showcased at the "*From Material Design to Research*" exhibition, organized by the bottom-up group SID (Società Italiana di Design), *Design4Material*, held at *Saperi&Co*, Sapienza University of Rome, in June 2024 (Figure 7).

Conclusions

This article highlights the potential for implementing the *Material-Driven Design* (MDD) method (Karana et al., 2015) in transdisciplinary pathways for training biodesigners. Biodesign is a disciplinary field in the process of consolidation, operating at various levels of depth (Pollini, 2024). As such, a transdisciplinary approach involving collaboration between designers and scientists is not always the right path. However, approaches that facilitate close collaboration between design and science appear to be the most promising in addressing the complexities of contemporary challenges. In this context, it is crucial to define a framework of methods, tools, and approaches capable of fostering dialogue between the different "ways of thinking" of those involved, enabling the adoption of a transdisciplinary practice. The

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methodological evolution of the *MbM workshop*—from multidisciplinary and interdisciplinary to a transdisciplinary approach—is a tangible example of the aspirations proposed by Karana et al. (2015). Over its various editions, the workshop has evolved toward a hybridization of the design method and the scientific method. The *Transdisciplinary Material BioTinkering* (TMBT) *method*, developed from the educational experience described, was not pre-defined. Rather, as in *Research Through Design*, it emerged and solidified through the progression of design experimentation, evolving via practice-oriented dialogue among the disciplines involved. The TMBT method is reproducible and applicable in the field of biodesign education, particularly for biofabricated materials. In the experience presented, designer wore lab coats and entered laboratories, demonstrating their ability to make meaningful contributions to science. Scientists, in turn, entered design faculties, pencil in hand, proving themselves ready to collaborate through a different way of thinking. The multiple relationships established among the various disciplinary levels allowed the research group to reconcile the intuitive and abductive approach typical of designers with the inductive-deductive approach characteristic of science. The results reveal that the dialogue between the "ways of thinking" of designer and scientists, while preserving the specificities of each, enriches and nourishes both perspectives. By sharing codes, languages, and common future-oriented perspectives, this dialogue addresses not only how things *are* - the scientific method - but also how things *could* and *should* be - the design method

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Footnotes

[1] The Design4Material Network was involved in the workshop, composed of: Sapienza University's MaterialdesignLab in Rome (coordinated by Prof.ssa Sabrina Lucibello); The Soft Surfaces and Polisensoriality lab at Bari Polytechnic's (coordinated by: Prof.ssa Rosanna Carullo); Hybrid Design Lab at Seconda Università degli Studi di Napoli (coordinated by: Prof.ssa Carla Langella); Research Centre of Material Design Culture (MADEC) at the Design Department of Politecnico di Milano (Founded and coordinated by: Prof.ssa Marinella Ferrara and coordinated by: Valentina Rognoli); Design Sustainability Lab (Founded and coordinated by: Prof. Giuseppe Lotti and coordinated by: Marco Marseglia); Making Material of Politecnico di Milano (coordinated by: Prof.ssa Barbare Del curto); MATto Lab at Torino Polytechnic's (Founded and coordinated by: Prof.ssa Claudia De Giorgi and coordinated by: Beatrice Lerma). In particular, the following spoke at the workshop: Flavia Papile (Designer and Engineer, researcher in Design at Making Material POLIMI), Lorena Trebbi (Postdoctoral researcher in Biodesign), Tania Leone (PhD candidate in Design for Heritage and Knowledge Innovation at POLIBA) e Noemi Emidi (PhD candidate in Management, Production and Design at MATto POLITO).

[2] The workshop involved Antonio DI Giovanni's local company Circular Farm, which produces mushrooms for the food sector

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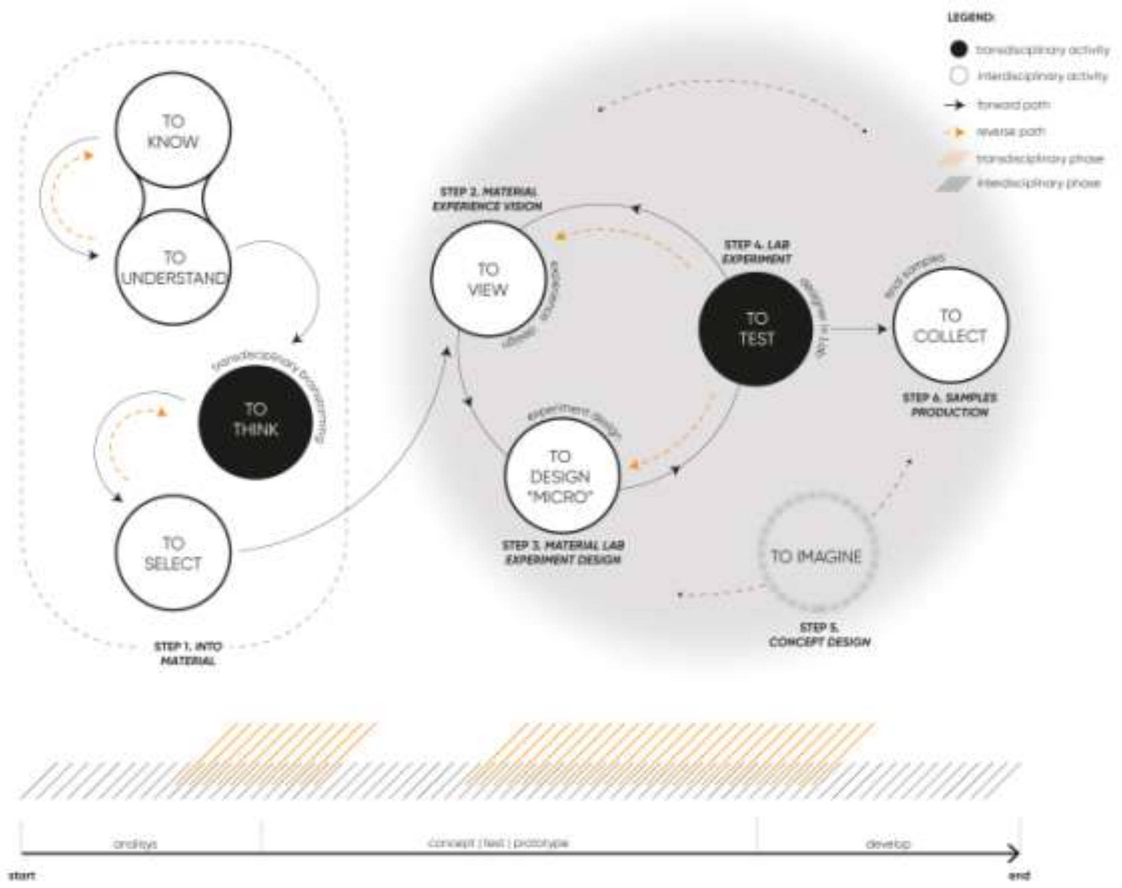

Figure 1. Transdisciplinary Material BioTinkering (TMBT) Method

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Figure 2. Pictures of the final show at Design Campus with student's works

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Figure 3. Pictures of the final show “UP TO THE CRAFT – Percorsi generativi” at “MIDA - Fiera Internazionale dell’artigianato 2023” with student’s works

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Figure 4. Participants engaged in the Transdisciplinary Material BioTinkering (TMBT) method during the MbM III - Biodesign Edition. Highlights include activities: a) To Know; b) To Understand; c) To Think; d) To Select; e) To View; f) To Design Micro; g) To Test; h) To Imagine, i) To Collect

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Figure 5. Biodesign Agenda - Transdisciplinary Tool

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Figure 6. The participants take on the role of "Designer in Lab" and, guided by a biologist, starting experimentation within a BSL1 (Biosafety Level 1) laboratory with *P. ostreatus*

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Figure 7. a) Final show at BASE Milano/We Will Design during Milan Design Week 2024 with student's works - Photo Credits Giulia Ficarazzo; b) Final show at BASE Milano/We Will Design during Milan Design Week 2024 with student's works; c & d) Final show at Sapienza Università di Roma at Saperi&Co

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