Pathway for designing with new DIY, circular and biobased materials: insights from three case studies

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Abstract. In recent years, evidence shows the depleting consequences of bad material application on our planet. This drove research to designing new substitutive and less-polluting materials. Materials derived from biomass, known as biobased materials, hold much potential as is shown in previous research. In addition, research efforts are also being made to help industrial designers work with these new materials. However, each of the supporting methodologies developed today focuses only on one piece of the bigger picture. This article examines three case studies of designers working with DIY, circular and biobased materials and highlights the similarities and contradictions of their design processes. Designing applications for these new materials mostly enacts in large systems. This explains why research on designing with new DIY, circular and biobased materials is in need to use many different complementary methodologies in conjunction, whilst still maintaining a structured and organized overview on the research. Therefore, a possible pathway is suggested to potentially support the designer in structuring, organizing and overviewing the complex research and development process of designing with new biobased materials. Ultimately, this study suggests that future efforts should be devoted to applying and validating the supportive pathway and embracing its open-ended and indeterminate nature. Conclusively, this article additionally uncovers the interesting bridge between the domain of designing with new DIY, circular and biobased materials and the designer's behaviour within.

Keywords: Design for Biobased Materials, Design for DIY Material, Design for Circular Materials

1 Introduction

Across the globe, environmental awareness is getting more and more its deserved attention. It is therefore crucial to explore acts that might contribute to the greater good of a positive human and planetary synergy. Herein, a sustainable development is the compilation of possible pathways that point towards sustainability as desired future objective, which has been recently represented by 17 global goals related to economy, society and environment. These three areas should be seen as integrated and nested in one another [1, 2]. Today, sustainability becomes a decision-guiding objective for

several actors and can be seen as a system property, raising from the interaction of different actors, rules, technologies, infrastructures, etc. [3, 4].
In this context, it is not yet clear how sustainable societies should look like and therefore the role of design and technology becomes critical. On the one hand, design is seen as a discipline capable of potentially supporting others while tackling complex, unstable, uncertain, often conflictual – in other words wicked – realities [5, 6]. On the other hand, industrial design is considered responsible for facilitating the creation and diffusion of unsustainable production-consumption patterns – "there are professions more harmful than industrial design, but only a very few of them" [7, 8]. Therefore, the role of design should be taken into account in its dual responsibility of influenced / influencer of bigger socio-technical systems [9]. If design has the ability to imagine and even facilitate that-which-does-not-yet-exist, Design for Sustainability specifically focuses on outlining actions and tools that have the potential to bring the societal transitions in line with the SDGs [4, 10]. Design for Sustainability (D4S) is multi-faceted, multidimensional and takes place at several levels where the framing of the problem and the scope of the intervention vary greatly, respectively from technocentric to human-centric and from insular to systemic [11].
With this objective in mind, this research situates within the domain of industrial design engineering, as concerned with the emergent DIY, circular and biobased materials, and it is driven by the questions: How do industrial designers approach these emergent DIY, circular and biobased materials?

2 State of the art

2.1 Materials and design

Usually material development is performed by material engineers, however in this case designers step in the process of materials development. Herein lies the potential of the designers to deploy their wide, multidisciplinary skillset to research the material development through design. So did Karana et al. introduce the Material driven Design (MDD) Method. Accordingly, this MDD method facilitates designing for material experiences [12]. Another design methodology, called 'Open Ended Design' is concerned with the changing nature of products and systems relative to and influenced by their surroundings and the way this methodology embraces those characteristics. Open Ended design has in this respect been introduced in relation to designing with DIY, circular and biobased materials. Herein, Open Ended Design can be seen as an unfinished design, where the definition of its characteristics is left open and therefore, flexible [13]. Within the realm of DIY, circular and biobased materials, is the Growing Design methodology also often used for biomass-growing materials more specifically. In this sense, Growing Design is a relatively new design practice where designers collaborate with biology. It is an intersection between design, materials science, biology, arts and crafts. The designers are trying to forge organisms and their processes by creating specific conditions to guide their growth into a specific material or product [14]. Lastly, since design with DIY, circular and biobased materials mostly aim at closing waste system loops, they all operate within the Circular Economy paradigm [15].

Ultimately, DIY, circular and biobased materials research shows that all of the above is not particularly new, considering many research is already channeled towards the domain of designing with new biobased materials and the seemingly wicked nature of systems in which they behave, which may lead to a need to create pathways for designing with them in a more organized, structured and orderly manner [16, 17]. In order to do so, this article examines three case studies which dealt with DIY, circular and biobased materials.

2.2 DIY, circular and biobased materials

DIY materials are bottom-up innovations, that allow quick experimentations with local resources. On top of that, DIY materials are not developed and designed with the purpose of replacing industrial materials, because this might be a long and expensive process. The field of DIY materials is even subdivided into five so-called kingdoms or categories, which are inspired by the first biological classifications [18].

Circular materials on the other hand, are materials that align to the concept of Circular Economy, they can be recycled, reused and/or have regenerative potentials [15].

Biobased materials are materials composed or derived in whole or in part of biological products issued from the biomass (including plant, animal, and marine or forestry materials) [19]. Elaborating on this definition from Vert et al., biobased materials are materials naturally grown, excluding the exhaustion of planetary scarce resources. It is this very aspect, together with many other benefits (i.e. biodegradability and other properties), that makes this research domain popular in recent years. Many efforts are hence channeled towards the creation of new, more performant biobased materials. Not to overlook the potential, new or alternative applications they can and will bring about. In this manner, many methodologies and frameworks have been introduced with the very purpose to support designers in their material application design process [12, 20–25]. It is important to note however, as all design tends to be flowing through a fuzzy front end procedure where many tools are deployed along the way, organization, structure and overview are key to developing new products or services, let alone designing with new DIY, circular and biobased materials. For this reason, this paper reviews and synthesizes three research case studies on application design with new DIY, circular and biobased materials. The objective of this research is to create insights on the similarities and dissimilarities of the design process of the three discussed case studies. Eventually a possible pathway is suggested to support design with these new DIY, circular and biobased materials in a more organized, structured and orderly manner.

3 Methodology

3.1 Research through design

In this work, *case study research* and, more generally *research through design*, are the overarching applied research methods. A major advantage of this approach, here qualitatively addressed, is its capacity to report on real-life contexts, where the design object and process becomes the center of our study. Specifically, the work of three design students, challenged to explore and design applications for new DIY, circular and biobased materials, have been observed and analyzed. Each design case studies had been documented by the students themselves in form of an unpublished extended abstract, where the design process is described in detail. For the here presented study, these extended abstracts are thoroughly read in order to achieve - case by case - a short list of insights on (1) the research question posed by the students ([a] application, [b] impact, [c] implementation), (2) the applied methodologies to find new application for the new materials and (3) the order of methodology deployment. It has been proceeded comparing the three cases seeking for similarities and dissimilarities regarding the three aforementioned points.

3.2 Case studies selection

All three cases derive from the curriculum of Industrial Design Engineering Technology of Ghent University, in Belgium. They have been developed in 2019 as master thesis projects. The three theses have been selected as case studies for this work because of their clear focus and engagement with the topic of DIY, circular and biobased materials. They each focused on developing and finding applications for a different material, with the commonality that all materials were not yet industrial nor readily available, therefore characterized by high uncertainty on their properties and possible applications – in other words ‘the materials have no identity yet’.

3.3 Case studies description

The three students’ design projects, analyzed as case studies in this paper were conducted in parallel over a course of one year. Each one of them focuses on a different DIY, circular and biobased material, namely: (1) a starch-based material developed from fruit- and vegetable waste, (2) a natural blueberry-based dye and (3) a naturally grown mycelium-based material in a biobased fibrous substrate. Also the goals of the theses were slightly different. The first attempts to develop and apply a new DIY and circular and biobased material from fruit- and vegetable waste, taking into account the complex system of waste salvaging to production, impact and implementation. The second focusses on designing suitable applications for a newly developed (and not yet industrialized) dye deriving from a very specific waste stream (blueberries) [26]. The third and last analyzed case, designs towards a specific application (a urn) for mycelium-based materials, where mycelium is the vegetative part of fungi [27].

4 Results

4.1 Case study research questions

Before going any deeper on the three case themselves, it is considerable to note already the nuanced difference within the focus of the case studies’ research questions. First, the case focusing on food-waste-based materials asks “How can fruit and vegetable waste be valorized in a full-fledged product, that is more environmentally friendly than its alternatives?". Subsequently, the case focusing on natural-dye states "This paper questions applications for a natural blueberry-based dye". Ultimately the case focusing on mycelium-based materials wonders "How can a mycelium-based funeral urn be implemented into a business model?". Compiling those three research questions, this article differentiates between [a] the exploration around the application of the material only, [b] the extra effort to define the comparative impact of the material towards the traditional competitors and [c] the final efforts to draft commercial implementations of the identified applications.

4.2 Case study methodologies and order of deployment

Starting up: initial unknowns and uncertainties.

Typical for new material application design, is to first get familiar with the new material at hand[20]. Cases 1 and 2 mentioned an experimental period in their design process, where the DIY materials are made by the design students in collaboration with field experts. Here, different material compositions are tried and documented. Desk research is performed in the field of the new materials. All of this until a basic understanding of the new material technology is established. This process is actually referred by one case study as 'exploratory design'. Exploratory design is the approach to immerse in a topic and all of its facets with the purpose to narrow down the options [20]. The remaining case 3, which did not mention such preliminary process, did however mention having prior knowledge of its material from a previous course.

Moving forward: following the Material-driven design methodology.

Having some basic knowledge on the new materials, the three designers took different methodological paths in their remaining design process. Furthermore, from this point the focus of their research question will drive their methodology deployment significantly. Although all three of the studies proceed with a similar design process, addressed in the next paragraph, they employ different, but equally valid methodologies with similar purposes. The key aforementioned process following on the exploratory design, is an overarching methodology as well, called the 'Material Driven Design (MDD)' Method [12]. Although this methodology is in its literature of origin specifically used for material design, all three research case studies applied and extended it to their material application design. Underlying are methodologies employed to characterize the materials, and subsequently design with their respective characteristics. So do case studies 1 and 2 express a process of testing their materials on their technical properties, i.e. physical, mechanical, thermal, optical properties, processing energy, durability, recycling, end-of-life, etc. Besides the technical properties, do all three case studies also express having investigated their materials' experiential characteristics. In this, previous studies have shown and strongly state that this part must not be overlooked, because it is as crucial as the technical characteristics in order to make a successful, pleasing and good appealing product [12, 21, 25]. Looking more deeply in the crucial step of characterizing the experiential properties of the materials, divergence emerges within the methodology deployment between the case studies. In the first study with fruit- and vegetable waste, the experiential characteristics of the material had been determined through the combination of existing supporting theories and the conduction of user tests. So did the Meanings of Materials (MoM) model prove to be helpful - in case study 1 - in generating a map of all variables that contribute to the meaning attribution of a person to a material [21]. This model indicates that the sensorial and experiential material properties lack, but also the participant‘s mood and the material meanings. Eventually, Semantic Differential Scales prove to be an excellent tool to collect this data [28]. The second case however, goes more in depth with the application of the MDD methodology. This case study conducted user tests, followed by determining the design intentions by means of creating a material experience vision. Ultimately, material experience patterns are manifested to convert the experiential meanings towards a material application field. This second case study thus followed the MDD method more meticulously. The third and last case study did not refer in particular to the MDD method in this subsection, but did however follow a similar path. Kansei engineering was introduced to develop products that match consumers' preferences based on their kansei requirements [29]. The basic idea of kansei method is that; the customer's feelings and preferences are being explored already at the idea generation phase in the product development process, which then facilitate the project later with final intended product communication. Ultimately, using 'experience mapping' the design intentions for its material application structured the conceptual intentions of the designer [30].

Finalization: identifying and testing possible applications.

Proceeding to the application design, each student applied a typical iterative and evolutionary approach to their whole design process. Creating an application field list that complies to all previous research outcomes, developing one application as an example, testing and validating its intentions and iterating again on the received feedback.

Two case studies pushed their research beyond the scope of application design. The mycelium-based case study (case 3) additionally researched the possibility to implement its material application in a business model. The food-waste case study (case 1) on the other hand went even further by also evaluating the materials' application impact on the environment using a comparative Life Cycle Assessment (LCA) approach, compared to substitutive products [23, 24]. Also, stated by one case study (case 1) of substantial importance as a methodology was 'Systems thinking', applied through a tool called 'System Archetypes'[31, 32]. Systems thinking supports designers in overviewing the interconnectedness in their design process and the environment in which their project behaves. This is an important tool in evaluating the impact of any design action and maintaining an overview.

4.3 Bridging the respective insights to the designer's behaviour

Having addressed the highly uncertain – even with no-identity – character of DIY, circular and biobased materials, which on top are not industrial, nor readily available; and besides that the key insights in form of commonalities and differences in design process approach; it is interesting to note and maybe even study the behaviour of designers within their design process. Questions around their behaviour arise, when wandering what designers drive to working with these new DIY, circular and biobased materials, since these materials must not be approached as the readily available, mass produced, commercial materials which everyone is familiar with in everyday products. On the contrary, these materials demand a whole different angle of attack in order to deploy them well within their scope of unique property compositions. Just as 3D printing technology found its way into industry, although with limitations to mass production; a way will need to be found for designers to pick up these DIY, circular and biobased materials through changes in their behaviour.

5 A possible pathway to design with new DIY, circular and biobased materials.

The results of this study are the insights derived from the commonalities and differences within the design process of each of the three students. In addition to these resulting insights is a possible pathway suggested to support designers in their design process with DIY, circular and biobased materials. So does the differentiation between the three levels of focus already suggest a key important insight for the development of this supportive pathway. A second insight regards the similar deployment of a first stage, referred as the exploratory design, which is a crucial must for any new material application research. After exploratory design, is the need expressed to start designing from material knowledge. Meaning its characteristics, both technical and experiential. The data derived from this phase in the design process will help to design with meaning. A central methodology expressed to be of influence in all three case studies is the MDD method. Although MDD includes both technical and experiential properties, it is important to notice that MDD behaves in a wider context. This is also stated by Karana with the 'Meanings of Materials' model (MoM) [21]. This model maps all the variables that contribute to the meaning attribution of a person to a material. Considering more specifically the experiential characterization of the new biobased materials, many methodologies can be used to determine and validate them with customers, i.e. Kansei engineering, Experience Mapping, etc. The purpose of new biobased material application design is eventually to create a list of requirements for its field of application.

Along with the exploratory design- and MDD process, are highly iterative and evolutionary prototyping methodologies employed, i.e. growing design, and many more.

Once the field of application is established, research might take the leap to develop an application and examine its impact compared to a substitute product. A well proven methodology suggested here is the comparative Life Cycle Assessment (LCA), which is ISO standardized.

Finally, research can evaluate the economic viability of the developed product by completing a Flourishing Business Model Canvas (FBMC). The flourishing business model canvas differs from the default one, through its attempt to not only capture economic data, but also societal- and environmental data.

Of course, as mentioned before, applying Systems Thinking will support the designer in analyzing the impact of his actions, as well as overviewing the interconnectedness of his project and its environment/surroundings.

Lastly, as is showcased with these three case studies, no design process is exactly similar and many methodologies are at the designer's disposal, leaving him with a plethora of options and choice. Not losing organization, structure and overview is of key importance to any design process. Keeping track of all the gathered data, the available methodologies and the check points in the design process is therefore crucial, whereby a suggestive – yet supportive- pathway is not an unnecessary luxury for any designer. In addition, it can serve as a focal point to indicate what to include and / or exclude from the scope of new research in the area of designing with new DIY, circular and biobased materials. Ultimately, all the aforementioned insights from the commonalities and differences suggests this possible pathway (Figure 1) for designing with new DIY, circular and biobased materials.

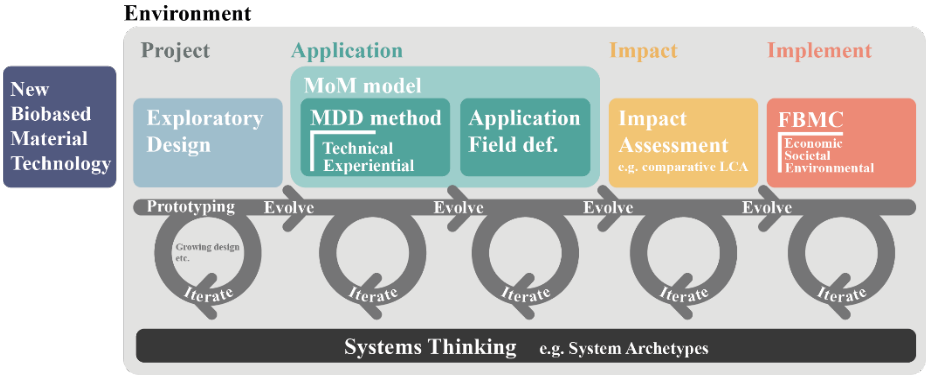

Fig. 1. Possible supportive pathway for designing with new DIY, circular and biobased materials

6 Discussion

Given the three research case studies over the course of one year and the insights derived from their design process, suggesting a possible supportive pathway, this work suffers from a number of limitations. First of all, the suggested supportive pathway is not empirically validated in new case studies. Secondly, this pathway is not definitive, nor trying to standardize the process of designing with new DIY, circular and biobased materials. Quite the contrary, this study encourages to embrace the open-ended character of this supportive pathway and shape it to your own needs in your design process. Thus if necessary, more complementary methodologies can and should be added in the future. What this pathway does however mean to bring about, is a critical thought on how to organize, structure and overview your design process and what aspects you could research on. This critical thinking about your process is essential in this field, as designing with DIY, circular and biobased materials has a broad context to work in. Furthermore, future validation will have to proof the purpose of the insights from this study and the suggested supportive pathway. In short, this open-ended possible pathway is purely directive and has, apart from the three case studies, not been empirically validated. Therefore, this reviewing study suggests future work to apply this open-ended pathway in new case studies within the field of designing with new DIY, circular and biobased materials, reflect on them and alter them to their needs. In addition, does this article articulate the interesting bridge to research the designer's behaviour in working with these new DIY, circular and biobased materials.

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