COHABITATING WITH LIVING MATERIALS: THE APPLICATION OF DESIGN FICTION TO SPECULATE ON BIOLOGICAL FUTURES

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ABSTRACT

COHABITATING WITH LIVING MATERIALS: THE APPLICATION OF DESIGN FICTION TO SPECULATE ON BIOLOGICAL FUTURES

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Designers are increasingly interested in understanding the relationship between materials and design. They are exploring innovative ways of producing objects and material experiences, especially with the influence of ongoing research and applications in sustainability. Further, developments in biotechnology are creating a new paradigm for materials and design within the term ‘biodesign’. Biodesign covers various approaches, from producing biofabricated materials to disclosing novel cohabitation possibilities with organisms. By focusing on the second, this thesis investigates the future of living materials to uncover cohabitation possibilities. Initially, a *sensitisation process* in the form of a field trip is carried out to complement theoretical knowledge with practical knowledge on working with living materials. Then, based on the literature and sensitisation process, a new qualitative workshop-based method, under *research through design fiction* approach, is developed and utilized to speculate on possible futures with living materials. The method involved nine participants in three teams carrying out a generative session. Based on the session, it is found that: a) the human side of people’s relationship with living materials is vital for achieving a sustainable mutualism; b) the temporality of living materials is an essential aspect of livingness that brings novel communication possibilities; c) living materials must be respected as beings, independent of their attributed value within human artefacts; d) the creation and nurture of living materials within the context of sustainability calls for alternatives to current theories. The research also confirmed that design fiction is a helpful tool for investigating biofutures, although refined ideation tools and more *reachable* methods, which can be based on those used in this study, are needed.

Keywords: Biodesign, Living Materials, Design Fiction, Speculative Materials

ÖZ

CANLI MALZEMELERLE BİRLİKTE YAŞAMAK: BİYOLOJİK GELECEKLER ÜZERİNE SPEKÜLASYONLAR İÇİN KURGUSAL TASARIM UYGULAMASI

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Tasarımcılar, malzeme ve tasarım arasındaki ilişkiyi anlamakla giderek daha fazla ilgileniyor. Özellikle sürdürülebilirlik alanında devam eden araştırma ve uygulamaların etkisiyle, nesneleri üretmenin ve malzeme deneyimleri tasarlamanın yenilikçi yollarını keşfediyorlar. Ayrıca, biyoteknolojik gelişmeler, malzeme ve tasarım için ‘biyotasarım’ terimi altında yeni bir paradigma yaratıyor. Biyotasarım, biyofabrikasyondan, organizmalarla birlikte yaşama olasılıklarını incelemeye kadar çeşitli yaklaşımları kapsıyor. İkinciye odaklanan bu tez, birlikte yaşama olasılıklarını ortaya çıkarma amacıyla canlı malzemelerin geleceğini araştırıyor. Başlangıçta, canlı malzemelerle çalışmaya ilişkin pratik bilgilerle teorik bilgileri harmanlamak için saha gezisi şeklinde bir *duyarlılaşma süreci* gerçekleştirildi. Ardından, literatür ve duyarlılaşma sürecinden baz alarak, *tasarım kurgusu yoluyla araştırma* yaklaşımıyla bir nitel yöntem geliştirildi ve canlı malzemelerle olası gelecekler hakkında spekülasyonlar üretmek için kullanıldı. Yöntem, üç takım halinde, toplam dokuz katılımcıyla, bir yaratıcı atölye şeklinde uygulandı. Atölyeden yola çıkarak şu sonuçlara ulaşıldı: a) ilişkinin insanları etkileyen tarafının düşünülmesi, mutualizmin sürdürülebilirliği için hayati önem taşımaktadır; b) canlı malzemelerin *geçicilik* özelliği, yeni iletişim olanakları için önemli bir faktör olarak öne çıkmaktadır; c) canlı malzemeleri, insan ürünlerinde atfedilen değerlerinden bağımsız olarak, varlıklarına ve canlılık haklarına saygı duyarak anlamak gerektiği görülmektedir; d) sürdürülebilirlik bağlamında, yaşayan materyallerle yaratmak ve materyallerin bakımı, mevcut sürdürülebilir tasarım teorilere yeni alternatifler gerektirir. Araştırma aynı zamanda, kurgusal tasarımın biyogelecekleri araştırmak için faydalı bir araç olduğunu ispatlamış ancak bu çalışmada geliştirilen gibi yeni fikir üretme araçlarına ve daha erişilebilir yöntemlere ihtiyaç duyulduğunun da altını çizmiştir.

Anahtar Kelimeler: Biyotasarım, Canlı Malzemeler, Kurgusal Tasarım, Spekülatif Malzemeler

To my mother

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LIST OF ABBREVIATIONS

ABBREVIATIONS

AD:	Architectural Design
CTC:	Cradle to Cradle
DfS:	Design for Sustainability
DIY:	Do-It-Yourself
GMO:	Genetically Modified Organism
HCI:	Human Computer Interaction
LCA:	Life Cycle Approach
LCD:	Life Cycle Design
MDD:	Material Driven Design
MDMS:	Meaning Driven Material Selection
MoM:	Meanings of Materials
MX:	Materials Experience
UX:	User Experience
PSS:	Product Service System
RTD:	Research Through Design
RTDF:	Research Through Design Fiction
SDG:	Sustainable Development Goal

CHAPTER 1

INTRODUCTION

This chapter will initially provide a background for the study. Then the aim of the research, the main research question and sub-questions will be presented. It will finish with an explanation of the structure of the paper.

1.1 Background

Design's role in society has started to change since the early 2000s, three decades after Papanek's (1972) predicted direction for the discipline due to changing problems that are becoming more complex and harder to approach. In line with this, industrial design practice is evolving and becoming more inclusive and holistic regarding a wide variety of design-relevant problems. The problems range from environmental outcomes of the recent production and consumption patterns to the societal problems that emerged from increasing inequalities. In other words, these are the 'real problems' of the world, which are changing the character of the design profession and opening up new and perhaps more necessary ways for designers to apply design theory and practice (Tischner & Verkuijl, 2008; Walker, 2006). However, it took time for the changes to appear in design expertise because the corporate role of the designer did not allow a designer to tackle such complex issues right away caused by the lack of collective knowledge among design practitioners, which used to be profit-focused (Walker, 2006).

As the changes in the discipline take place, inevitably, designers find themselves in a position of constant self-adaptation. The old school understanding of designers, which positions them between the producer and customer, has evolved into a conversation starter and a social pioneer (Stappers et al., 2011). The complex issues and the upgraded understanding of the discipline push designers to adopt new skill sets and working methodologies (Press & Cooper, 2003). For designers to adapt to countless different combinations of working environments, they have started to learn the required qualifications of the peculiar tasks from other disciplines. As a result, the designer started to become a part of a group of collaborations from different professions – a practitioner of interdisciplinary teamwork (Spence et al., 2001). As the profession's scope grew, designers found themselves in both very likely and unlikely cooperation with various disciplines learning very particular skills and practicing particular tasks.

Along the way, a likely and necessary association occurred between design and material science. The materials for design have been a long-studied subject since the very existence of the profession, and in fact, it was studied as a research area long before the appearance of design as a profession. When an idea in the mind of a human needs to be materialized, knowledge of material and material behaviour is considered a fundamental requirement for the act of design (Ashby & Johnson, 2013). Materials are vast in variety, and they require different techniques and processes to be embodied in products. They are fundamental elements in product design that directly affect the environment. The distinctions between each material and material group make them to be approached and evaluated within their specific ways of doing (practices) when it comes to environmental effects. Based on these environmental concerns, not just the production phase and the use phase, but also the disposal phase requires different ways of doing compared to what has previously been done. Therefore, material selection gains importance as environmental concerns and related societal problems flourish. Designers must elaborate their ideas to find a halfway between the proper usage of materials and a proper consideration of environmental concerns. Therefore, a necessary collaboration between industrial designers and material scientists is gaining even more importance, due to the problems of the world that are becoming even more complex in time. As these collaborations become prominent, designers get the chance to apply learnings gained from the knowledge produced by material scientists. On the other side, these contributions are not taking place in a single direction. Not only does the designer benefit from the material scientist but also the designer contributes to the field of material science and influences material scientists by taking an active role in the development of new and alternative materials. In this way, the designer brings a new perception to the field of materials and design by increasing and mediating the communication between material scientists and material users (Barati & Karana, 2019).

Apart from direct collaborations with material scientists, with the influence of developments in material technology, designers are seeking alternative ways to apply their 'designerly ways of doing' also for the development of new materials that aim to establish new experiences created by the meaningful embodiment of materials in designed artefacts (Karana, Barati, et al., 2015; Karana et al., 2014; Rognoli et al., 2015). Hence, there is currently the emergence of what is named the 'material designer'. The term Do-It-Yourself (DIY) Materials, coined by Rognoli et al. (2015), explains the method of such intention of the designer as collaborative or individual practices facilitated by the designer to make alternative materials or material applications. DIY Materials is an example of a whole new movement in materials and design – comprising developed or altered versions of conventional materials, a combination of materials, or completely new ones.

Another collaboration, this time a less likely one, has been formed between designers, artists, and biologists. Advancements in biotechnology have offered new possibilities to biologists to bring a new perspective within their field, welcoming designers and artists by allowing them to be more curious and to experiment with addressing 'the living'. One of the early controversial examples was designed by Eduardo Kac, Alba, the glowing rabbit. It became famous for loosening the boundaries between an artefact and the living (2000). However, the example opened ethical debates about using a mammal that has a nervous system in their experiment (Dickey, 2001; Philipkoski, 2002). The ethical arguments on genetic modification are still taking place, and they are increasing as we become more aware of harnessing the living and livingness in synthetic objects. However, if we put aside the genetic modifications, even without changing the genome, the ethical questions brought up by the use of living creatures would still be raised when they are used for any purpose of humans, even for a plant that lives inside a house.

Addressing the 'real problems', putting on top of the initial intentions and staying around the ethical conduct of the practice, designers have defined a new working area called 'biodesign'. Myers (2012, p.8) defines biodesign as *"... specifically to the incorporation of living organisms or ecosystems as essential components, enhancing the function of the finished work."* Coining the term helped designers who were already tackling living artefacts to theorize their practice and created a paradigm for new designers to focus on the matter.

Due to the materiality of the living and the organic connection between materials and living entities (living entities considered as materials), initially and dominantly, biodesign applications have taken place in achieving material innovations driven by achieving environmental sustainability in terms of production of artefacts using alternative materials (Camere & Karana, 2017). The sustainability-driven motivations for utilizing alternative materials were emergent for biodesign as material biofabrication to take place (Camere & Karana, 2018b). The motivations (in terms of sustainable development goals), such as finding low carbon/energy alternatives for using diminishing resource materials, reduced processing, reduced toxicity, increased circularity, etc., have driven the designers to be interested in material fabrication with organisms (Cogdell, 2019). On the other hand, despite such benefits that could be observed, the research in assessing the sustainability of producing materials with organisms in terms of design for sustainability (DfS) stays limited and is not clearly illustrated.

Also, earlier, biodesign was still unable to comprehensively cover the issues of ethics and achieving sustainability for the living due to its utilitarian approach to living and being over human-centred for a situation while working with another living being. As Ginsberg and Chieza (2018) argued, developments in biotechnology and design are leading the world towards the possible context where biologically designed artefacts are apparent; however, without systemic changes in anthropocentric ways of living, consumption patterns, and unethical demand, biotechnological solutions will eventually become problems like we face today. So, the elevated philosophy of biodesign created a transfer in understanding for designers by thinking of *living with them* instead of *using them*, which is the foundational position behind this research. Addressed as living artefacts as biodesign in this research, designers and researchers have extended the understanding of *designing with living artefacts* from material biofabrication also to include cohabitation with living artefacts where livingness and the qualities sourced from organisms' livingness become persistent material and/or artefact qualities (Karana et al., 2020). However, despite the elaborated ethical understanding (by approaching their livingness as something to be sustained) of designing with living materials, the absence of a concrete theorization for DfS approaches around living materials is also not visible in the second livingness approach. Significantly, the organisms which are a part of living artefacts rather than 'unliving' materials, the positioning of living artefacts stays within the boundaries of life cycle design and circularity in terms of DfS approaches which are too broad and ambiguous to cover the living artefacts in depth in terms of design and sustainability. However, as one of the main motivations for cohabitation possibilities, the 'preferable' futures in which we cohabitate with living materials and sustainability of and with living artefacts keeps their prominence.

Design research that deals with cohabitating with living entities that are not other humans, animals or other such species, but rather biological entities that have been harnessed for a functional or expressive gain (living artefact as biodesign, livingness approach) is state-of-the-art and not extensive. As stated by Karana et al. (2019), what was once considered impossible is becoming possible with the advancements in technology, material development, and production; however, the current approaches in design tend to be unequipped to implement such advancements, so designers must instead be proactive in exploring possible new methods and tools to work with new materials that are alive, active, and adaptive. This being the case, emerging design research methods (such as *design fiction* used in this research) potentially provides an efficient set of tools for investigating the future of biodesign, particularly if the applied practices of biodesign stay beyond reach. Furthermore, cohabitation is a term that has multiple ends that affect different cohabiters. The related literature and the developed projects primarily focus on the well-being and the maintenance of the living artefact; however, the human perspective as owners, caregivers, or custodians of living artefacts has received relatively little study, when everyday design limitations such as cost, design criteria, technological abilities etc. become comparatively less of a concern.

1.2 Aim and Scope of the Research

Environmental sustainability is a contemporary and urgent topic that impacts on a large proportion of design research where production, ownership and consumption cycles are involved. There are different ways to target the issue; however, as a design researcher, I believe that the most fundamental answer to the question of 'what can be done?' lies beneath the studies that take place around the subject of materials, due to the substantial effects caused by their tangible nature. Apart from that, during my undergraduate and graduate education, I became more aware of the new practices that would make a difference on the issue, and I was intrigued to follow the less discovered ones, which eventually sparked my interest in designing with living materials and biodesign. The practice of biodesign is becoming more widespread as biotechnology accelerates; however, the field is still in its infancy. Research is based mainly on conceptual developments initiated by design researchers, with relatively few commercial applications. Moreover, the requirement of multidisciplinarity, the limitations, and the requirements make the topic hard for an independent designer and/or design researcher to launch the process of research and development, leaving aside commercial resources and applications.

Referencing my thoughts above, what has been studied, and their limitations, the research reported in this thesis was conducted to investigate biodesign as a new discipline to envisage and work towards more habitable near futures that involve cohabitation with living artefacts and environments. However, it is vital to set the boundaries within ethical conduct and recognize the living artefact as much as the human being to achieve that goal. That is why the research handles the living artefact as not solely a design artefact but a living creature that humans cohabitate with. In this context, product design is the practice that can allow and ease the maintenance of such cohabitations with living materials.

Living materials can offer many novel experiential values to be incorporated into a product but have themselves various needs based on their own livingness. So, for my thesis, I researched the relationship between humans and living artefacts (i.e., products in which a living entity exists as an essential element of the product). To do so, for my empirical studies, I pursued a *research through design* approach, and for that, I preferred to use design fiction to investigate human practices around cohabitation scenarios and try to seek answers to how such relationships would be possible in the future with current global challenges and opportunities that the future may hold. Since design fiction possesses an efficient set of tools for investigating the future of any human concept and allows free thinking regardless of everyday design constraints, it has potential as a tool to deal even with a subject which might be the most tangible aspect of industrial design (materials). Despite being tangible, the novelty of biodesign and living materials research yields high potential to be approached through design discourse. Therefore, from one perspective, being an emerging field creates a difficulty in terms of researching biodesign in an applied form due to lack of facilities, newness of skillsets etc.; from a contrasting perspective, the emergence of biodesign makes the area still so undiscovered, creating an ideal subject matter for speculative methods.

Consequently, **this thesis aims to investigate the future of designing with living artefacts using design fiction methods by exploring the possible speculative experiential potentials, cohabitation possibilities, practices, and attitudes when we switch from inert products and infrastructure to biologically alive replacements.**

1.3 Research Questions

In order to achieve the intended aim, the following questions are posed to guide the research.

Main research question:

- *How might the characteristics of living materials be directed to benefit functional and/or experiential qualities of product designs in the future?*

Sub-questions:

- *How strong is the support or reluctance for a future in which we cohabit and build mutualistic relationships with artefacts embodied with living materials?*
- *What can design research and product design offer to help envision and achieve cohabitation with living artefacts and increase human acceptance?*
- *What are the possible future contexts where humans possess a custodian role for living artefacts?*

1.4 Structure of the Thesis

The thesis has been constructed in seven chapters: Introduction; The Road to Living Artefacts (Literature Review); Methodology; Phase I: Biodesign Sensitisation; Phase II: Design of the Generative Session; Phase III: Analysis of the Generative Session and lastly; Discussion and Conclusions.

Here in the first Chapter, I present an introduction to the study with its background; I provide the aim and the scope of the thesis along with the research questions; then complete this chapter with the structure of the thesis.

In the Road to Living Artefacts (Literature Review) Chapter, I explain the relevant literature to support my thesis. Broad areas include the changing scope of industrial design practice regarding materials and the new relationships between material, design, and experience. Then I focus on one such new relationship, adding biotechnology to the cluster, namely biodesign. Then, I differentiate the earlier approach in biodesign from the latter approach, which is more on conceptualizing livingness (Karana et al., 2020) and the potential it carries regarding the future of human-living material interactions.

The Methodology Chapter outlines the research approach and methods for collecting and analysing empirical data for the research. The research includes three consecutive phases. First, understanding working with living materials and biodesign sensitisation. For the second and main empirical data collection phase, I designed a design fiction workshop focused on cohabitating with living materials, using the knowledge I have gained from the literature and sensitisation process. In the final phase, a discussion has been carried out regarding support and reluctance for a future in which living artefacts are part of our environment.

In the final Chapter, I discuss the results of the research and their implications for the various stakeholders involved in living artefact design and adoption. I also present my main conclusions of designing with living artefacts. Then I conclude my thesis by explaining the limitations of the research and my suggestions for further studies.

CHAPTER 2

THE ROAD TO LIVING ARTEFACTS

This chapter has been organized to progress from general topics to the specific subject matter of living artefacts. It begins with a new understanding of the industrial design discipline in relation to materials. First, it seeks an answer to the question of 'what has changed in industrial design concerning materials?' with the impact of changing professional understanding within and differing concerns of society, and then continues by consolidating the answer to the initial question by introducing several emergent paths in materials and design. Then, as one of such paths, it dives into the realms of material driven design approaches and as in the first part, it shows the revision of the old understanding to the new by defining a new relationship between materials and designers. Afterwards, the area of biodesign and, more specifically prolonging livingness of the living materials to the use phase is discussed. The chapter ends with a summary of key points extracted from the literature review and a declaration of the gap in which my subsequent empirical studies will be positioned.

2.1 Materials and Design

> *"We live in a world of materials; it is materials that give substance to everything we see and touch. Our species – homo sapiens – differs from others most significantly, perhaps, through the ability to design – to make things out of materials – and in the ability to see more in an object than merely its external form"* (Ashby & Johnson, 2013, p.3).

The ability to shape materials allowed humanity to thrive as a species on Earth. It is impossible to claim a purpose behind the first shaping of material; nevertheless, it is possible to claim that very mundane practices are the main drivers for such an act. In line with the evolution of genus homo, the development of tool making, and material shaping has become apparent significantly. The need for new materials grew stronger as the products for human utilization became more intricate in time, allied to the development of technology. Especially in the late nineteenth century in Britain, the Industrial Revolution played a tremendous role in shaping our way of living and created a pathway where creating more complex objects is possible. As complexity became a norm for designing a machine that manufactures a product, the complexity of manufactured goods has also increased. In 1968, in his film *2001: A Space Odyssey*, Stanley Kubrick created an analogy through the film's editing by implying within the diegesis the transition from the first tool used by the ancestors of homo sapiens and a highly developed spaceship that is apparent in the year 2001 (see Figure 2.1) (Kubrick, 1968). It is argued that the scene represents the human advancement of using tools and, hence, shaping of materials.

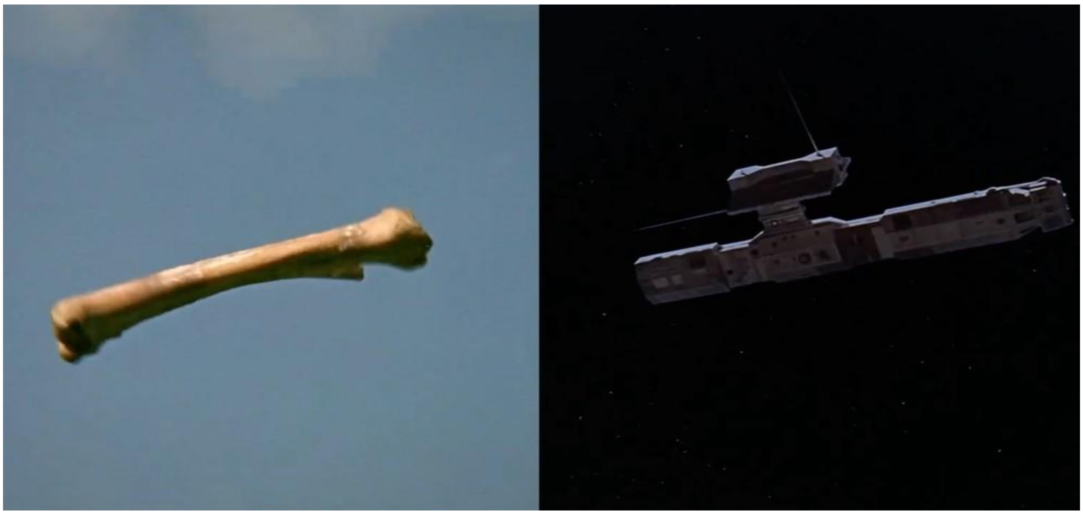


Figure 2.1 Bone to Spaceship (Gahyun Lee, 2018, as appeared in Kubrick, 1968)

Being amongst the professionals responsible for material embodiment in manufactured goods, designers led people to meet complex products full of different processed materials and varieties of sub-components. Although the initial applications of materials in product design were primarily based on either functional or aesthetic (especially visual) value, later, it became the industrial designer's duty to satisfy both requirements simultaneously (Ashby & Johnson, 2013). One of the reasons for the rise in teamwork in design is the increased complexity and diversification of sub-components for products, beyond the capability of any single designer. However, the materials knowledge that could be obtained by designers remained limited to those materials tied to the goals of mass production and form-giving (Ashby & Cebon, 1993, 2007; Ashby & Johnson, 2013; Lefteri, 2014; Manzini, 1986), despite talk about applications of new generations of materials (Brownell, 2017). Due to the disconnects between material science and design, the functional qualities of materials persisted as the prominent driver for new material applications and commercial exploitation (Barati & Karana, 2019).

Moreover, such disconnections remained in the professional area and in design education, where material selection has been seen up until recently as a highly engineering-led domain (Pedgley, 2010a, 2010b). The answer to these problems, however, cannot be solved with just a snap of a finger; instead, it requires long-haul strategic methods to overcome the problem, addressing the different needs of design students compared to those who are studying in engineering or science departments (Akın & Pedgley, 2016; Asbjørn Sörensen et al., 2017; Pedgley, 2010a, 2010b). One of the attempts to answer to the differing needs of design students - and in some cases, designers - is increasing designers' first-hand exposure to materials, through samples accumulated in material libraries (Akın & Pedgley, 2016). Nevertheless, it is arguable that material libraries cannot stand as the sole solution for the designers to understand materials better, especially when considering constraints of physicality, practicality, and logistics. So, like material libraries, profound yet more reachable updates need to occur first in design education, and afterwards in professional design practices.

The evolving relationship between materials and design can be observed in reducing or eliminating the materialization of a product. Under the influence of technological advancements, the ability to design functional digital interfaces which can replace tangible products has opened up new dilemmas for both designers and users and left questions about the necessity of a product. The idea of finding sustainable solutions without using any additional raw materials has sparked designers to increasingly seek out system-level solutions that can be realized digitally rather than tangibly. As a result, the definition of industrial design or, in other words, the understanding of what industrial design has to offer, has evolved. This evolution has led designers towards product-service system (PSS) design, which is considered a more comprehensive approach to satisfying users' needs, involving a tangible product conceived within a wider system, or indeed no product at all (Diehl & Christiaans, 2015). Product-service systems have proved to be useful in achieving sustainability on a personal level, allowing people to save energy and time by putting less effort to maintain product usage, upgradability, etc. (Marchand et al., 2010). In line with these developments, the World Design Organization has upgraded the definition of industrial design to include experiences, systems, and services along with tangible products (WDO, 2015). Accordingly, the scope of industrial design has been upgraded, which previously was mostly related to the design of tangible products. Another example, compiled in 1959, *the 100 best-designed products of the modern era* by Jay Doblin, the Director of the Institute of Design at the Illinois Institute of Technology (IIT) in collaboration with Fortune Magazine, conducted a survey with the participation of 100 top designers of that era to list what was considered to be the best designs up until 1959 (Doblin, 1970). On the 60th anniversary of the list, in 2019, a recompilation was made by scholars at IIT Institute of Design and Fortune Magazine, following the methodology of Doblin as closely as possible (Weil et al., 2019). When the two lists are examined, the change in what is accepted as industrial design becomes evident. The focus of the 1959 initial list was on tangible products, with a share of 98%; whereas in the list of 2019, a 29% share was for service and system-related design (Weil et al., 2019). In further developments, PSS is combined with design for social innovation (Manzini, 2014, 2015; Manzini & Meroni, 2007; Meroni, 2008), which has resulted in carrying the PSS paradigm one step forward than design for social innovation and proposed an emerging strategic design approach called transition design (see Figure 2.2) (Irwin, 2015, p.229) - referring to the design of (or for) change and *"design-led societal transformation."*

Figure 2.2 Transition Design (Edited from Irwin, 2015, p.231)

It is also important to inspect design and materials from a more sociological perspective. Since the initial focus of industrial design was more on the incremental increase in consumption (Margolin, 1998; Papanek, 1995; Walker, 2006), it is useful to look to consumption theory to explain the usage of resources, in this case, materials and design. Also, the term *material culture* stands out for representing the various objects that humans define as relatable to themselves. Material culture extends to the utilization of these objects, spanning storage, use, carrying, wear, etc., from which an object is ascribed meaning within the practices in which it is a part of (Hodder, 1994). Though from the sociological perspective, the term *material culture* refers to the physical artefacts that compose culture and give meaning to human acts, everything physical, whether it carries cultural connotations or not, is made out of materials. However, until the increase in consumption studies became more apparent after the late 1980s, the linkage between material culture, consumption theories, and material resources was not seen clearly (Warde, 2015). Significantly, studies regarding the patterns of ordinary consumption opened up new debates on the relationship between material culture and material resources. Ordinary consumption stands for the consumption acts we perform daily, regardless of context and whether conscious or not, to maintain our lifestyles (Kleine III et al., 1993). It is practiced by spending a high amount of resources that can be observed in the most ordinary acts like eating; and that need for resources, which appears to be insignificant, is not as trivial as it appears due to the repetition of the act (Padovan et al., 2015; Warde, 2015; Welch & Warde, 2015). Following studies on mundane practices, theories of sustainable consumption emerged. Sustainable consumption in summary is a social theory that promotes the practicing of social acts where the usage of resources is apparent with sustainability in mind (Jacobsen & Hansen, 2021). It helps make the linkage clearer between materialization of products and material culture, since the theorization of sustainable consumption is partly based on the extraction and usage of material resources. Based on the above, 1) it is possible to assess the extraction and usage of materials as a part of sustainable consumption. 2) It is possible to connect *material culture* - which is an important part of social identity creation – to mundane and therefore sustainable consumption. Consequently, when these two clusters come together, it becomes possible to state that the materials embodied on products could have the power of reflecting the social identity of people.

Handling the issue in terms of product semantics, selecting materials for a product comes forward as one of the most prominent ways to convey a particular message through a product (Krippendorff & Butter, 1984). Product semantics is explained as the field that investigates the symbolic character of a product conveyed via its form, usage, and context, as it appears both in the individual's mind and within the social context (Butter, 1989; Demirbilek & Şener, 2003; Krampen, 1989; Krippendorff, 1989; Krippendorff & Butter, 1984, 2008). A product cannot be considered bluntly as an embodiment of raw materials. The upscaled version of the primary personalistic view is expressed by Ezio Manzini in the book *The Material of Invention*, stating the obligation of cultural acceptability of a material within a society (Manzini, 1986). Initially, the meaning of material contributes to the meaning of a product and enhances the user's experience by addressing the senses that have been contextualized and transformed into a framework for designers (Karana et al., 2009). The Meanings of Materials (MoM) model has been introduced to the literature to create a framework for designers to wriggle outside the conventional material selection norms through by considering the sensorial properties of materials alongside the meaning they evoke in the user's mind (Karana et al., 2010). In a related study, Karana (2010) instructs designers to seek their evoking patterns of materials by looking at the specific user group for the specific object in the specific context and time to come up with meaningful material and product experiences (Karana, 2010).

2.1.1 Design for Sustainability (DfS) and Materials

Initially, the first environmental considerations arose at the beginning of the 1960s when a biologist drew attention to the usage of harmful pesticides in their book (Carson, 1962). However, using sustainability to define environmental and societal considerations and prospects took about ten years subsequently (Kidd, 1992). As defined by Cambridge Dictionary, the word sustainability means *"the quality of being able to continue over a period of time."* By the same dictionary, the evolved version is *"the quality of causing little or no damage to the environment and therefore able to continue for a long time* (Cambridge Dictionary, n.d.)." The latter definition is rooted in the publication Our Common Futures by the United Nations (UN), also known as the Brundtland Report, which mentions sustainability in the term *sustainable development,* defined as *"development that meets the needs of the present without compromising the ability of future generations to meet their own needs* (Holden et al., 2014; WCED, 1988, p.43)." As of today, however, when used solely, the term sustainability is losing its meaning as the term becomes too vague and broad to convey any particular meaning. This mainly has two reasons, one positive and one negative. First, negatively, it has started to be used for purposes that do not involve any actions towards the well-being of either the environment or society, instead as a general definition for so-called being conscious of the environment and/or of society. As an example, a phenomenon which is called *greenwashing* can be given: Its name is based on the contrast of companies' perceived environmental actions by the public and the actual actions behind the curtains which aim to make a brand or a company look as if they have environmental considerations to gain profit out of the fake image (Szabo & Webster, 2021). Second, positively, sustainability appears in a broadening perspective in almost every discipline towards environmental and societal problems. Starting from 2013 with six, then increasing to seventeen, the United Nations proposed Sustainable Development Goals (SDGs), which define a variety of detailed actions for disciplines to participate within, with the aim of prioritizing the emerging problems of the environment as much as a society (Griggs et al., 2013; Sachs, 2012; UNGA, 2015). Although it is not easy to position an intention under one SDG very strictly, since each goal often complements others, nevertheless within this thesis, SDG 12 *Responsible Consumption and Production*; and SDG *11 Sustainable Cities and Communities* are of most direct relevance to the drivers of the research. Defined by the UN, SDG12 is maintaining sustainable production and consumption patterns through the actions that take place both on individual and corporate scales; and SDG11 is transforming the human residences to become more sustainable and inclusive (UNGA, 2015).

The scope of sustainability widened and became more inclusive with the joint development of various disciplines. The design field, which was mainly there to increase profits, gradually transformed into a practice where social and environmental innovation is considered equally important as making profits (Manzini, 2014). Research and practice on 'design for sustainability' (DfS) branched into many sub-categories and expanded its scope over time (see Figure 2.3) (Ceschin & Gaziulusoy, 2016). Again, like the SDGs, it is not possible to put an intention under a specific category of DfS due to the complexity of the design process, which involves various factors from production to disposal, but there are eminent categories within the focus of this research. However, the categories shortly mentioned may fail to comprehensively cover what has been focused on in this research, since designing with living artefacts is a very recent and underdeveloped area and can propose a new category on its own for DfS research.

Nevertheless, the categories provide a background for emergent areas such as designing with living artefacts, namely: 1) product life-cycle focused ecodesign and 2) nature-inspired design intentions, which are cradle-to-cradle (CTC) and biomimicry. Ecodesign, also known as *Life Cycle Design* (LCD), is a paradigm that concentrates the mind on environmental effects arising from a product's life cycle, starting from the extraction of raw materials until the disposal phase of a product (Alting, 1993; Bhamra & Lofthouse, 2008; Vezzoli, 2014). So, despite being generic, LCD is not a surprise for material-focused research relying on ecodesign. CTC, on the other hand, is still a life-cycle focused approach where the life cycle is intended to be *closed* by re(using) the inorganic product or product parts in various ways and/or allowing the organic parts to decompose easily so the energy consumption and waste density would be minimized for environmental well-being. Lastly, in biomimicry, the main aim is to mimic natural systems of differing scales from cells to organisms and even ecosystems, focusing on forms, functions, and mechanisms to increase sustainability (Benyus, 1997). Furthermore, in terms of material selection, biomimicry can be a tool that offers alternative routes for material development (Volstad & Boks, 2012). Caution is needed however, since mimicking nature or the natural systems found within nature does not necessarily provide advantages for sustainability (Ceschin & Gaziulusoy, 2016). From this perspective, designing with living artefacts is not an act of mimicking. Instead, it proposes alternative hybrid classifications that blur the boundaries between the natural and human-made (Myers, 2012).

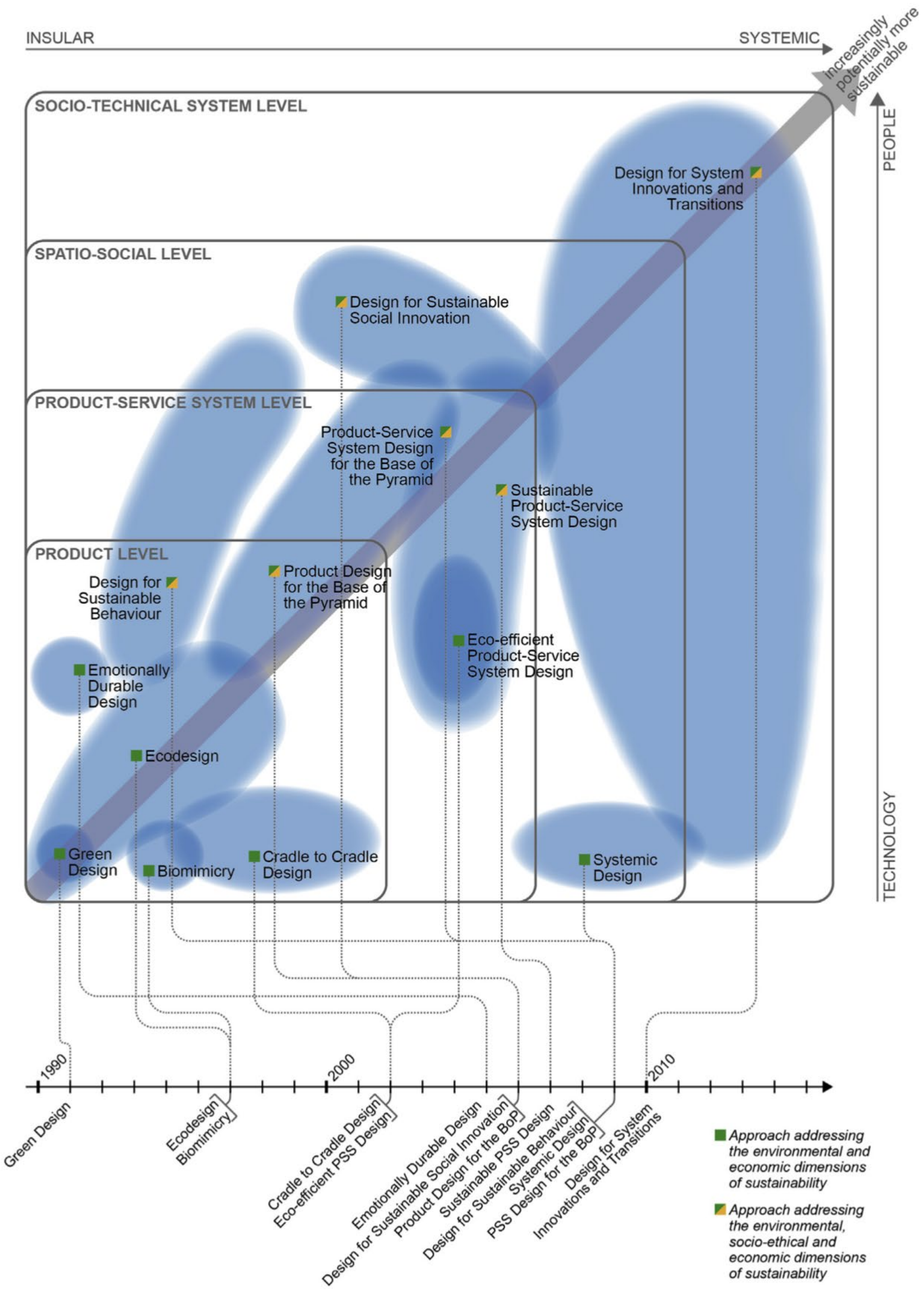


Figure 2.3 The DfS Evolutionary Framework (Ceschin & Gaziulusoy, 2016, p.144)

Sustainability considerations related to product design initially started with life cycle assessment approaches in the middle of the 1990s, where the product's material was the focal point (Margolin, 1998). With the emergence of PSS at the beginning of the 2000s, the focus, which was on the usage of resources (in this case, materials), also started to include the product's presence within a designed system and include a broader framework which was a milestone in DfS research and practice (Mont, 2002). In fact, after the introduction of PSS design, material selection did not lose its importance in terms of DfS; instead, the PSS instituted new ways of carrying out material selection by allowing designers to consider material selection as a part of a whole system. It resulted in the design of the life cycle itself along with the product's positioning within that system (Vezzoli, 2014). Within the framework of PSS, Vezzoli (2014) defines four principles of material sustainability for product design:

- Using as few material resources as possible.
- Using safe and nontoxic materials.
- Considering renewability and biodegradability while selecting.
- Considering the extension of the lifetime of materials, including re(using).

Further, earlier statements by (Walker, 2010) can be added to the initial four:

- Decreasing complexity and keeping materials as close as possible to their natural state.
- Using local materials that are found in the local environment.

2.1.2 Materials Experience

Materials experience (MX) broadly covers the user's experience of materials both personally and functionally, including sensations, evoked meanings and perceived emotions when materials are embodied as products. As a research field, materials experience leads designers and design researchers to create meaningful experiences with and through materials (Hekkert & Karana, 2014; Karana et al., 2008, 2010, 2014; Karana & Hekkert, 2010). The term has its roots in both the developments of material selection for design and the emergence of user experience. As explained in the previous sections, there have been numerous books published for material selection in design, mainly on conventional methods referring to the issue as an act of *choosing* a material from amongst multiple possibilities. Two books are notable for creating a basis for materials experience as an area research and practice. First is Manzini's *Material of Invention*, where he created the very first connection between materials and user experience (Manzini, 1986). Second, published initially in 2002, is Ashby and Johnson's *Materials and Design* (2013), where the interdisciplinarity of materials and design is emphasized, along with the role of material selection in creating product identity (Karana et al., 2014; Karana, Pedgley, et al., 2015; Pedgley et al., 2021). However, the term 'materials experience' has was not coined until 2008, referring initially to the user's experiences of a product's material (Karana et al., 2008). The scope of the term expanded from merely the perception of the user to the holistic viewing of the material-focused design processes, including the designer who is the seeker of the meaningful material experience, as well as exposition of the factors in choosing or creating the suitable material for designated experience (Karana et al., 2014). For designated experiences, the designer aims for the most suitable material to use the experiential and functional qualities of a selected material (Karana & Hekkert, 2010).

Materials experience is deeply connected to the user experience (UX) field. According to an earlier theorization of a product's characteristics, pragmatic attributes shape a character based on its utilitarian aspects and hedonic attributes positioned by the subjective meanings based on the user's perspective (Hassenzahl, 2003). In an elaborated and clearer ordered version of Hassenzahl's model, Anderson (2011) created a pyramid hierarchy of needs model, which describes maturity levels of a (UX) design and shows a relationship between experiential qualities and the functional qualities in terms of UX (Figure 2.4). The pyramid starts with the functionality, which is the objective-driven basis of the pyramid. It narrows with increased quality in the functional part of the design until the dashed line in the middle of the pyramid is reached. Then, further narrowing is made to show increasing quality of the experiential side of the design, reaching a peak when a design becomes *meaningful.* When considered together, the pragmatic attributes of the model align to the bottom of the pyramid, whilst the hedonic attributes align to the top.

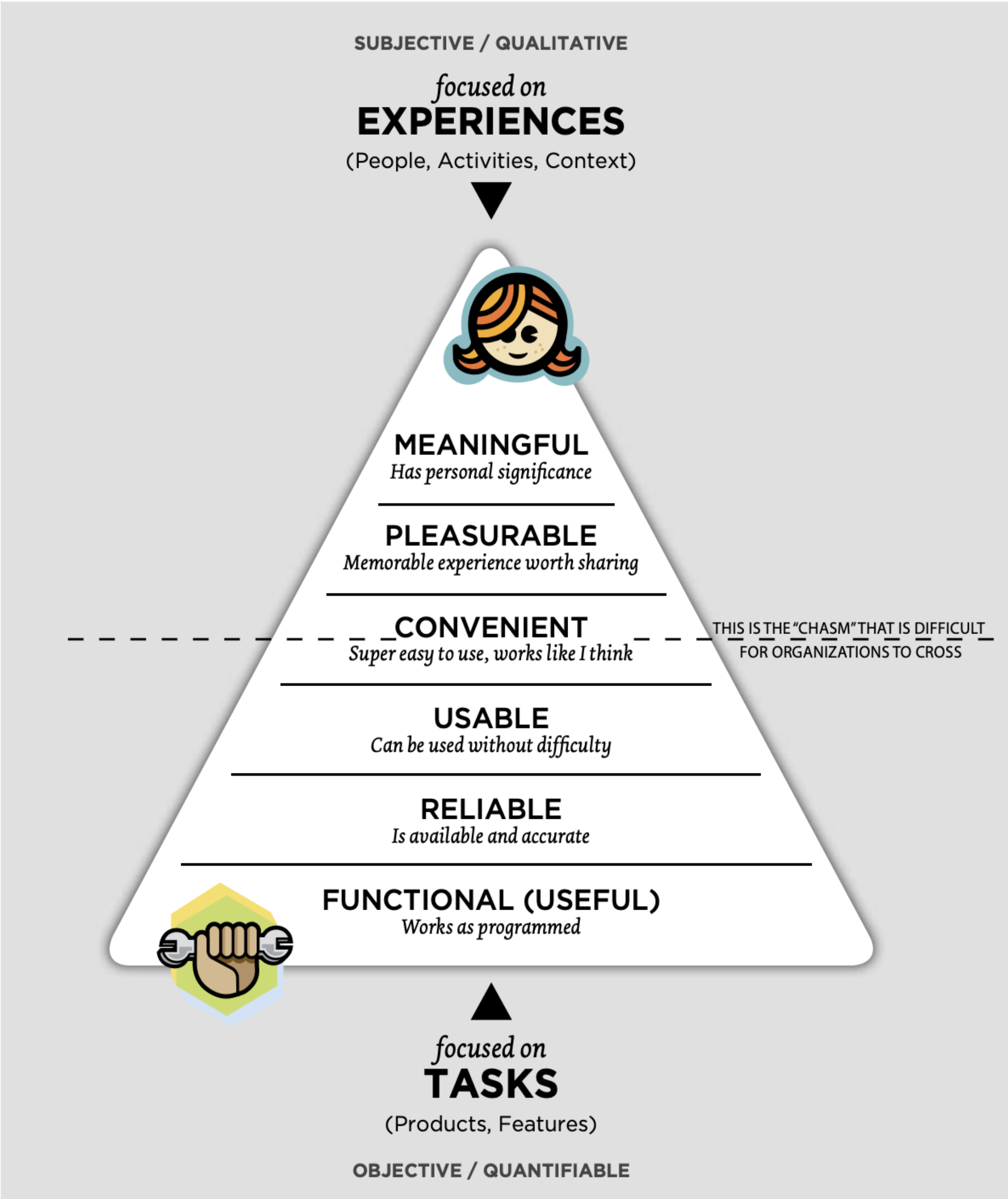


Figure 2.4 User Experience Hierarchy of Needs Model (Anderson, 2011, p.12)

Pedgley and Şener (2021) merged features of several existing UX frameworks to propose an interaction-based UX quadrant framework, drawing upon: 1) the theories of Hassenzahl (2003), who differentiates pragmatic and hedonic needs; 2) Desmet and Hekkert's (2007) user-product interaction map, which illustrates emotional experience affected by aesthetic and semantic experiences; 3) Crilly et al.'s (2009) work on HCI and UX, regarding the affective, cognitive and behavioural outcomes of interaction with a product; and lastly, 4) Anderson's (2011) pyramidical hierarchy of needs model. The quadrant framework is shown in Figure 2.5, where the classifications (aesthetics, meanings, emotions, and actions) are shown without hierarchy and are interconnected in a way that each classification has chance to affect, and be affected by, the other three (Pedgley & Şener, 2021).

Figure 2.5 Interaction-based UX Quadrant Framework (Pedgley & Şener, 2021)

Coming back to materials experience, apart from functional qualities, which are intrinsic to the material itself, experiential levels were identified first by Karana et al. (2008), and later extended, through addition of a performative level, by Giaccardi and Karana (2015). In combination, the four experiential levels establish an individual's materials experience. Each level is compatible with the UX quadrant framework of Şener and Pedgley, developed as an assistance to 'design for interaction' (DfI) challenges (2021).

- Sensorial Level (Aesthetics): We perceive the material properties through our five senses that constitute our initial encounter. Examples: shiny, hard, loud, smelly, bitter, etc.

- Interpretive Level (Meanings): The first level of interpretation of the materials is defined through attributed meanings by adjectives. Examples: masculine, sexy, brave, etc.

- Affective Level (Emotions): The second level of interpretation of the materials is triggered unconsciously. Related to emotions and affected by our cumulative thoughts. Examples: surprising, impressing, disappointing, disgusting, etc.

- Performative Level (Actions): The final level of four and the collective outcome of the prior three levels. Sensorial, interpretive, and affective levels cause us to respond differently to the embodiment of a material. It is the level that describes how we act around a material and explains how the material influences us to do what we do.

These levels are affected by numerous factors. For example, based on the doctoral dissertation by Karana (2009), the interpretive level is affected by forms, the product with its utilization, user, and the context where the product (and material) is positioned. So, since the first level of interpretation is affecting the subsequent ones, it is not possible to reach definitive results or predictions of materials experience. Different interpretations come from a) product aspect (form and function); and b) user aspect (gender and cultural background) (Karana, 2010; Karana & Hekkert, 2010). On the other hand, usage of some materials may to some extent be generalized due to cumulative usage of the materials in similar contexts (Hekkert & Karana, 2014).

As attention to materials experience increases, not only do new ways of doing emerge by the involvement of the designer in the material development process, but also the inclusion of designer can help materials science to connect with end-users through the application of contextualization skills brought by the designer (Barati & Karana, 2019). Apart from professional utilization, the integration of MX to the early stages of design education helps students to link technical material properties to the experiential qualities, more easily allowing them to create a deeper understanding of materials rather than the act of *choosing* them (Pedgley et al., 2016). Regarding the future projection towards MX both in design education and professional execution, two forthcoming topics drive the designer to follow a materials experience approach and be a part of material development: sustainability (for an ecological transition in materials) and technology (opening new design possibilities) (Karana et al., 2016; Pedgley et al., 2016). These are also the main drivers of this thesis.

2.1.3 Material Driven Design

Material Driven Design (MDD) is a foundational, material-focused, and experience-oriented product design approach that defines a framework for designers to expand the process of material selection and to come up with meaningful material experiences for end-users (Karana, Barati, et al., 2015). MDD framework creates a methodology for designers to directly engage them in the material development process, compared to being only the choosers of a given material. The MDD process takes place within three different scenarios:

- Designing with a developed and well-known material.
- Designing with a developed but less known material.
- Designing with a semi-developed material, or a material proposal.

The process can be summarized in four steps within the mentioned scenarios (see Figure 2.6):

I. Understanding the material potentials. This is the process by which a material's physical and experiential qualities (sensorial, interpretive, performative, and affective levels) are understood. a) Physical characterization is done through the material tinkering process (a material is exposed to different experimental tests such as burning, bending, cutting, etc.) so that the technical characterization of the material can be completed, and the designer can understand its properties. b) Experiential characterization is done through, first, the experiential characterization by the designer and second by the intended user group, using qualitative methods such as questionnaires, surveys, focus groups, etc., to have an overall view of the material's experiential qualities (Giaccardi & Karana, 2015).

II. Creating materials experience vision. This is the step to understand the shared and differing aspects of the material among different users. The process is carried out to understand the context in which the material can be used meaningfully, and hence towards creating meaningful experiences in a specific context. The step eases the designer's material decisions by focusing on specific technical and experiential qualities that arose in the intended user group and shows a proposal of an interaction between the product and user.

III. Manifesting materials experience patterns. Understanding how users would like to experience the material from their perspective is the main aim of this step. The Meaning Driven Material Selection (MDMS) method involves the designer collecting data from the users to understand the material's meaning. This is carried out so that the designer can specify connections between the properties of the material and the meanings evoked from user interaction (Karana & Hekkert, 2010).

IV. Creating product and/or material concepts. This final step involves collecting and evaluating the outcomes of the previous three steps and using them to create meaningful material experiences embodied on product and/or material concepts.

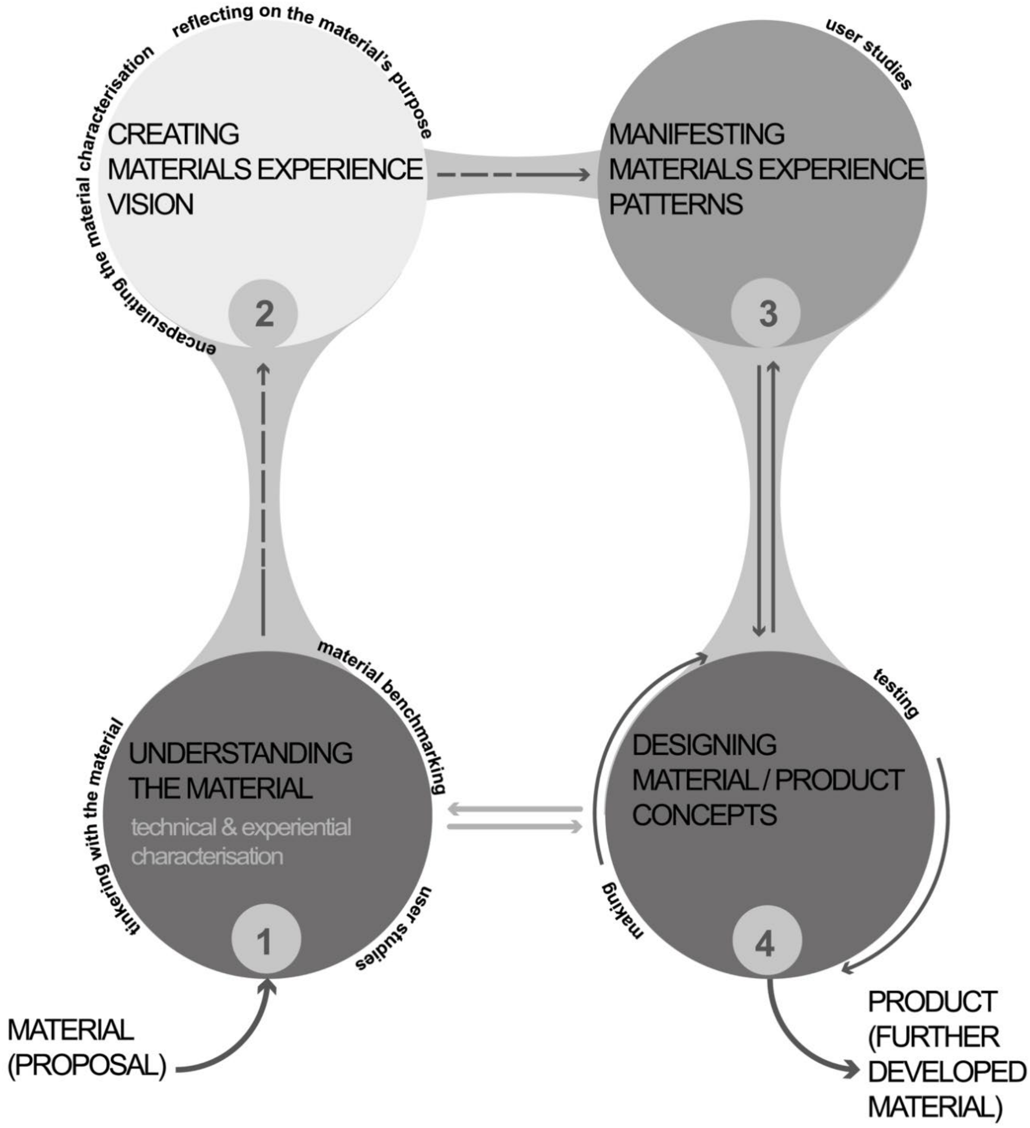


Figure 2.6 Material Driven Design (MDD) Method (Karana, Barati, et al., 2015, p.40)

Apart from creating meaningful material experiences, the MDD Method it is also an essential tool for the designer to explore the various potentials of materials. Barati and Karana (2019) introduce The Material Potential Framework and categorize these potentials as follows:

- Form as Materials Potential
- Function as Materials Potential
- Experience as Materials Potential
- Affordance as Materials Potential

The first two can be considered the most ‘conventional’ categories studied by many design scholars and design practitioners (e.g., Ashby & Cebon, 2007; Ashby & Johnson, 2013; Brownell, 2017; Lefteri, 2014). Materials experience (MX) is a relatively new concept (Hekkert & Karana, 2014; Karana, 2010; Karana et al., 2008, 2014, 2016; Karana, Pedgley, et al., 2015; Karana & Hekkert, 2010; Pedgley et al., 2021) compared to the first two, as discussed earlier in this chapter. Affordance as Materials Potential on the other hand, is a new concept, introduced by Barati and Karana (2019), but having its roots from Gibson’s introduction of the term *affordance* (Gibson, 1977) which was later adapted to design by Norman (1988, 2013). The MDD contains unexplored novel affordance potentials due to the nature of the MDD process, and such potentials are inclined to arise due to a) spontaneous discoveries during the MDD process; b) the new and sometimes unique techniques that are used for MDD processes and; c) recontextualization of a material, considering what is a non-material or *hacking* material properties or production methods (Barati & Karana, 2019).

2.1.4 DIY Materials and the Material Designer

The open design and the democratic design movements that emerged in the early 2000s have influenced designers to share personal knowledge and experience with other designers and non-designers (van Abel et al., 2014). Later, creating and storing such collective knowledge became easier with the expansion of the internet, and the act of design became even more democratized; allowing everyone to adapt products based on their needs, and sometimes to take part in the design process, hence empowering people to become co-designers and co-creators (Richardson, 2016). Another yet similar point, the increasing accessibility to production methods, the bursting technology, and the ease of information access, made personal fabrication widespread (Bull & Groves, 2009; Mota, 2011). Mota (2013) coined the term *open materials* (http://openmaterials.org/), which augmented the open design principle to include designer-led material creation practices, creating a concrete basis for DIY (Do-It-Yourself) Materials research.

DIY materials are one of the fruits of the democratized design and personal fabrication movements, and relatively a new phenomenon that theorizes the material driven explorations that are carried out by the designer(s) who use -and sometimes invent- their methods, techniques, and material outcomes during the exploration period (Rognoli et al., 2016, 2021; Rognoli & Ayala-Garcia, 2021). Just as in the MDD method, material exploration/development must not be necessarily completed for the undiscovered materials; the materials can be developed versions of conventional materials or modified materials as much as the new ones. As in MX and MDD, *learning by doing* stands as the most prominent principle in DIY materials, so it is possible to state that those three approaches feed each other, and together they create a solid framework for practice-led material explorations in design, hence creating a new role of the material designer. Lambert and Speed (2017) states that the process is more valuable than the result because it yields a higher amount of knowledge, is simpler to grasp, and is more inspirational regarding the practice-oriented self-driven approaches in materials and design.

Compared to conventional manufacturing processes brought by the industrial revolution, DIY materials manifest a different kind of approach regarding product aesthetics. Since the materials are created or adapted with the self-abilities of the designer in self-convenient facilities, the outcomes tend to be different compared to commercially manufactured products, which often exhibit precision, excellent surface qualities with a high level of technical capabilities. Yet, as suggested by Lambert and Speed (2017), DIY materials hold inspiring and educative values within. Appreciation of the aesthetics of imperfection arises with the spread of self-production practices, even though it was considered as appealing before industrialization (Ayala-Garcia & Rognoli, 2017). It is something desirable today, to some if not all, with its uniqueness, personalization potential and the naturalness obtained intentionally or unintentionally (Pedgley, 2014; Pedgley et al., 2018). The DIY materials can be counted as one of the sustainability practices under the notion of self-creation and naturalness of the imperfect aesthetics that strengthen emotional ties, thus making the outcome more strongly tied to its creator (Ostuzzi et al., 2011; Rognoli et al., 2016). Apart from the surface quality, when biobased components are selected as raw materials, the experience of naturalness of the end material increases. The processes of creating DIY materials from bio sources lends the method to be described as *cooking materials* by design scholars and practitioners due to its cooking-like features: the recipe (the instructions and the list of ingredients to produce the end material); the ingredients (the raw materials planned to compose the end material); and the utensils (the tools to produce the end material) (Rognoli et al., 2015, 2021; Rognoli & Ayala-Garcia, 2021).

It is observed that designers design their materials based on their sources or ingredients, so DIY materials are categorized based on the raw materials that are used in the composition. There are five categories (kingdoms) of DIY materials; however, any given designed material can span multiple categories (Ayala-Garcia et al., 2017; Ayala-Garcia & Rognoli, 2017):

- Kingdom Vegetabile. The primary source of the material is derived from plants and fungi. The materials are often grown or harvested. For example, Hemp Chair by Werner Aisslinger, 2015
- Kingdom Animale. The primary source of the material is derived from animals and microorganisms. The materials can either be an outcome of a

collaboration with a living organism or parts of animals. For example, Ruminant Bloom by Julia Lohmann, 2004

- Kingdom Lapideum. The primary source of the material is minerals, such as natural stones and ceramics. For example, Marwoolus by Marco Guazzini, 2015.
- Kingdom Recuperavit. The primary source of the material is waste of any kind. The wastes can be both industrial or domestic and can be sourced from the waste of inorganic materials and organic materials. It is the biggest category based on the number of cases (Ayala-Garcia & Rognoli, 2017). For example, Project Pomace by Aşut et al., 2020.
- Kingdom Mutantis. The primary source of the material is a hybrid combination of interactive, smart, and industrial materials formed through technology. The combination of materials from precedent categories falls under this category. The materials in this category have different experiential potentials such as dynamism, responsiveness, and performative potentials such as increased strength, etc. For example, Morphing Pasta and Beyond by by Morphing Matter Lab, Carnegie Mellon University (Tao et al., 2022).

2.2 Defining "Bio" in Materials

In materials in design literature, there is not a clear understanding of what 'bio' stands for, especially when combined with other words. It is caused by mainly three reasons: first, the biology-related design practices are in their infancy to comprehensively define a clear definition; second, the issue of combining the word bio with other words (e.g., materials, design, fabrication, etc.) creates vague and too broad practices to define clearly and third, such combinations of words such as biodesign and biomaterials are often used by other disciplines. Moreover, they have been used by the other disciplines before the intention of design scholars and practitioners, resulting in misconceptions when a designer is first introduced to the subject. As a novice researcher in the design field, I was challenged by the issues I just mentioned, which led me to write a section covering this issue. Therefore, I will explain the 'material side of bio' in this section and biodesign in the following sections since the latter does not refer directly to materials.

The Cambridge Dictionary (n.d.) defines the prefix 'bio-' as *"connected with life and living things,"* highlighting the inclusion of the principle of 'livingness' when something is referred to as bio, defining a phenomenon or an object as it involves livingness at some point. Apart from being a prefix, the combination of *bio*- with a modifying word such as design, roots from the field of biology, and more specifically, the advancements in subcategories of biology such as synthetic biology, biotechnology, and bioengineering, which has allowed the design of living cells. However, the same scientific advancements made the designer's involvement in the process possible, often not at the cell level but rather at a bigger (artefact) level, by combining such artefacts with living systems. Another relationship occurs when *bio*- is combined with material; biomaterials are defined by medical, material, and biomedical scientists as the materials that are suitable to be used for or with organic tissues (Zhang & Williams, 2019). Biobased materials created by material scientists refer to bioplastics, biofilms, biofibres and biocomposites (Vinod et al., 2020). From a designerly point of view, on the other hand, apart from the design of medical equipment, both biomaterials and biodesign can be refer to design with (or for) biologically driven materials, and thus has a strong link to DIY materials. The differing approaches of disciplines make these terms varied in scope and outcomes, especially when the varying skillsets of disciplines are considered.

Nevertheless, clarifying the adaptations of these terms from other fields to design carries crucial influence for a designer to internalize the topic. Moreover, there needs to be a more explicit categorization between a *design* and a *material* when the entanglement and misconception of *bio*- are considered. From a designerly point of view, in their report *Understanding 'Bio' Material Innovations: A Primer for Fashion Industry*, the company Biofabricate categorizes biomaterials as follows (Lee et al., 2020) (see Figure 2.7).

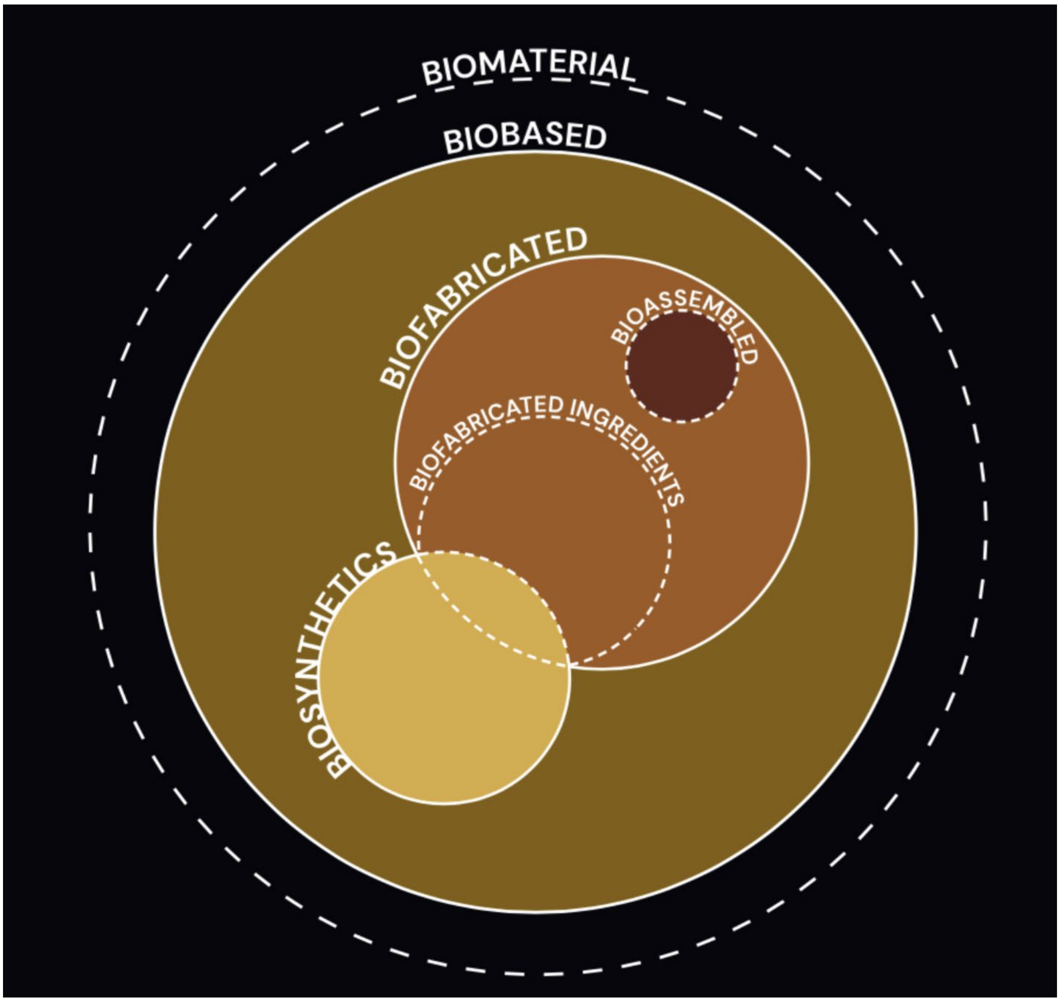


Figure 2.7 Understanding 'Bio' Material Technologies (Lee et al., 2020, Executive Summary Section)

- Biomaterials. Too vague and broad in definition, often being used to refer to biobased materials in design literature (e.g., sub-categories) or non-bio derived but rather bio-compatible inorganic materials purposed for medical and dental industry (e.g., implants, regenerative medical practices, dental equipment, heart valve replacement, etc.).

- Biobased materials. Different from biomaterials, biobased materials explicitly refer to material that is derived from an organism or plant in any state (e.g., conventional biotic materials: leather, silk, wood, etc.; organic waste, natural fibres, natural polymers).
- Biofabricated materials. The material itself is produced by the living cells. They are either bioassembled by the living cells or can be ingredients for biosynthetic materials.
- Bioassembled materials. Materials produced by living cells which result in a structure without any further chemical processes (e.g., mycelium structure, bacterial cellulose, etc.).
- Biofabricated ingredients. Ingredients that need further chemical processes to create a structure (e.g., milk proteins, lactic acid, etc.)
- Biosynthetic materials. Synthetic, polymer materials produced by further processing either a biobased material input or a biofabricated ingredient (e.g., bioplastics, lactic acid into PLA, milk proteins into milk fibres, etc.)

From this point onwards, I will be referring to materials in any association with living organisms as biobased materials because the precedent categories are too general to specify specific attributes and then living materials as I proceed.

2.3 Prior Design Approaches Involving Biology

Before delving into the final destination for this chapter -designing with living artefacts- three forthcoming approaches that fostered biodesign theoretically and practically should be elucidated briefly: first, biomimicry; second, cradle-to-cradle and circular design; and third, biophilic design. As explained earlier in the thesis, biomimicry and cradle-to-cradle are some of the main approaches in DfS (Ceschin & Gaziulusoy, 2016), and share similar notions to designing with living artefacts

(Camere & Karana, 2017). They are often entangled with materials in design. On the other hand, biophilic design is mainly studied under architectural design.

2.3.1 Biomimicry

Nature has always been a role model for the design of objects since the very first act of design. Initially, and for a very long time, the main idea was to mimic natural systems. Although the goals to mimic the natural systems have changed and evolved throughout the years, taking nature as a resource to design has remained the same. Despite being conceptualized relatively recently (Benyus, 1997), the idea of mimicking nature as a strategy for design has existed for thousands of years (Das et al., 2015). A relatively early example, studies by Leonardo da Vinci on flying structures suggest that the studies are based mainly on the observations of birds and bats (Kennedy, 2017) (see Figure 2.8). Biomimetics was initially coined by inventor Otto Schmitt in the late 1950s, who created analogies between biology and technology, highlighting biology's potential for transferring ideas to technology (Bhushan, 2009; Kennedy et al., 2015).

However, the conceptualization of the term *biomimetics* for design purposes took forty years. One of the intentions was to increase the lifetime of a design outcome and decrease environmental impact, as much as increment performance (Benyus, 1997). Benyus (1997) transformed the term biomimetics - which was considered a more engineering and material science-driven field - into something less technical and comprehensive (DeLuca, 2014), namely 'biomimicry'. He defined the term with three primary meanings: 1) nature as a source of inspiration; 2) nature to outline what is appropriate; 3) nature as a source of learning. Then, in 2006, Benyus co-founded The Biomimicry Institute and later asknature.org, which led to increased collaboration between biologists and practitioners, allowing practitioners such as designers to apply nature's ways of getting things done to everyday objects.

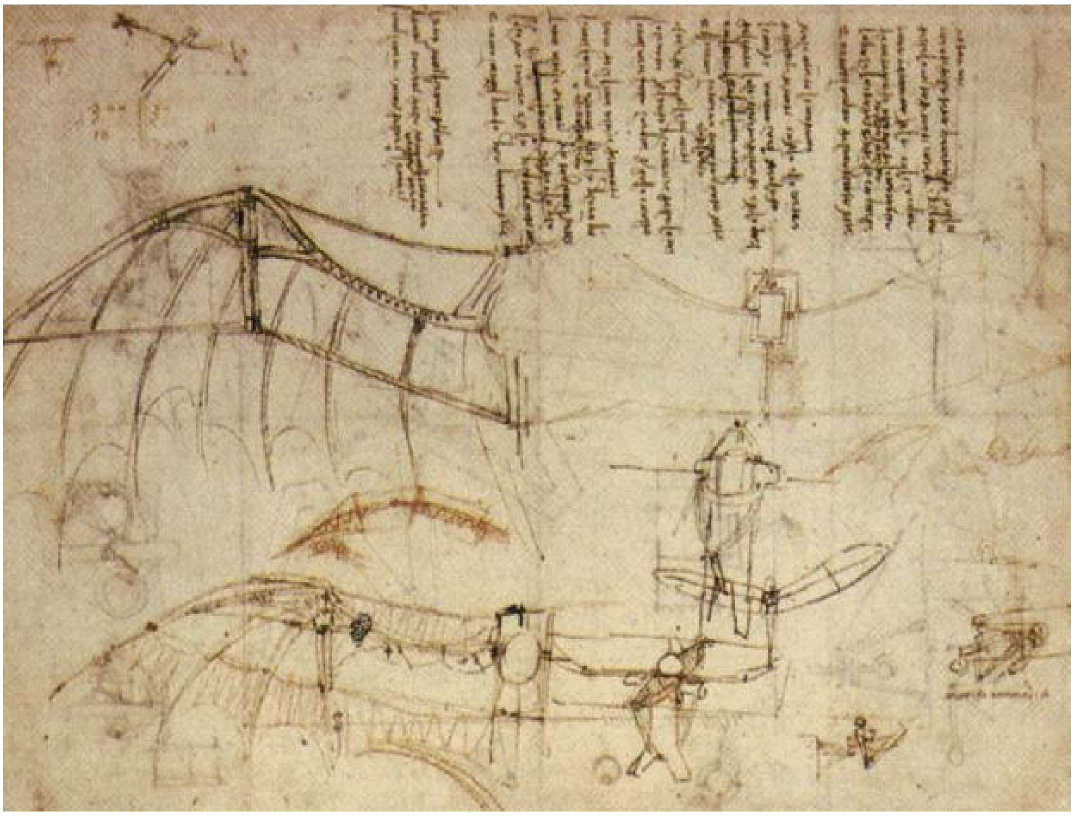


Figure 2.8 Design for a Flying Machine (da Vinci, c.1488)

2.3.2 Cradle to Cradle and Circular Economy

Cradle-to-cradle (CTC) is a DfS-driven approach that was born as an interpretation of LCA (Life Cycle Analysis). It ideally aims to transform the linear life cycle of products that end in landfill into a circular loop where the product(s) or product components are reintroduced at suitable stages within the loop without creating waste (Braungart et al., 2007). It is based on the theory of McDonough & Braungart (2010), who interpreted biomimicry holistically at the PSS level and transformed the term cradle-to-grave into cradle-to-cradle by adopting eco-effectiveness and regenerative(ness) rather than eco-efficiency of LCA (Bakker et al., 2010; Bjørn & Hauschild, 2013). Therefore, it is a biomimetic approach where the natural cycles that are observable in nature are imitated. Within this framing, CTC proposes two different types of components to be evaluated: biological nutrients and technological nutrients (Braungart et al., 2007). Biological nutrients are the organic materials that can be decomposed in soil without harming the environment; technological nutrients are the inorganic components which do not have any adverse effect on the environment and can be used (reintroduced to the loop) continuously without losing quality. Many organizations and governments have embraced the model, so eventually, the pioneers of the approach, McDonough and Braungart, initiated the Cradle-to-Cradle Products Innovation Institute, which became a life-cycle assessment certification authority for organizations (CTC Products Innovation Institute, n.d.). Five categories exist for the assessment of products/designs under CTC: safety of materials; product circularity; clean air and climate protection; clean waters; and social fairness.

With the foundation of the Ellen MacArthur Foundation in 2010, an updated interpretation of the concept, namely Circular Economy (CE), was introduced in 2013 (Ellen MacArthur Foundation, 2013). With the growth in awareness and urgency of the UN's Sustainable Development Goals, it became more critical to define ways of not just targeting but also achieving those goals (Schroeder et al., 2019). As a model, CE benefits highly from CTC by interpreting it as a set of tools to achieve circularity, hence creating an economic model for a functioning system with various scales such as households, residences, cities, countries, etc. The model proposes benefiting from the CTC approach to achieve regenerative processes for everything that has been produced, and like CTC, it aims to achieve environmental sustainability through design at the PSS level. It enhances restorative usage of materials, products, and/or product parts by reintroducing them into the loop, allowing the system - in theory - to become waste-free (Geisendorf & Pietrulla, 2018) (see Figure 2.9).

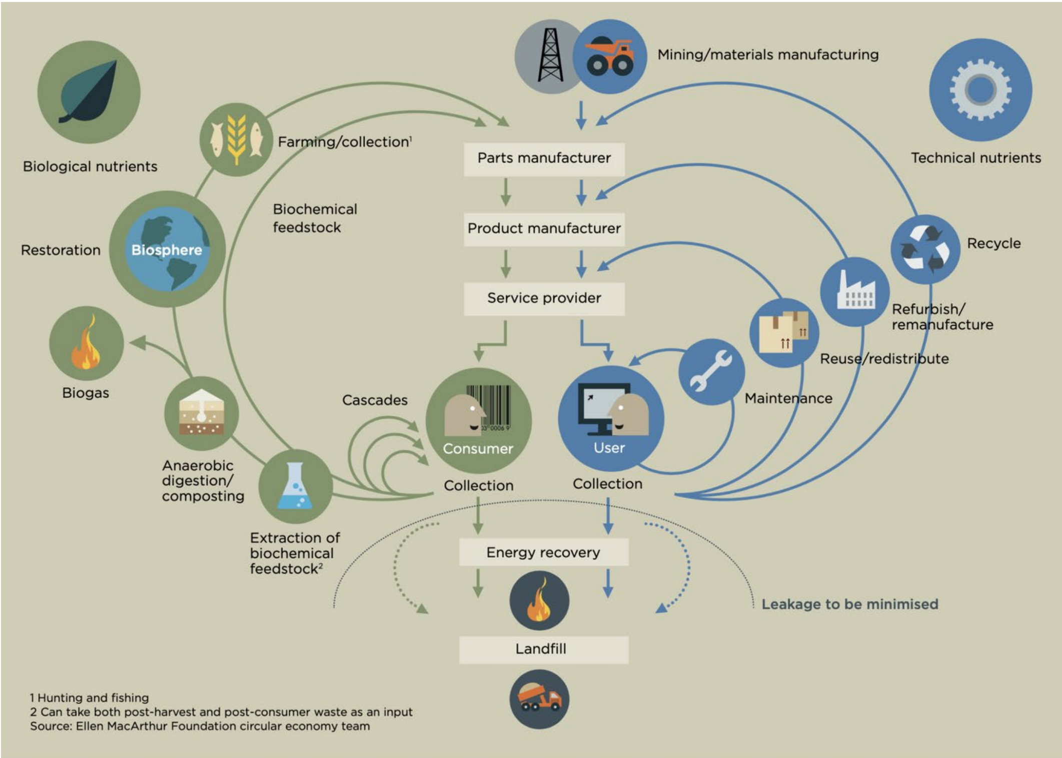


Figure 2.9 The Circular Economy (Ellen MacArthur Foundation, 2013, p.24)

With the same goal of achieving a circular economy, 'circular design' is often interchangeably used with CTC; therefore, they share very similar notions (closing the loop, reintroduction of materials, regenerative design) and support each other. On circular design, Medkova & Fifield (2016) state that it is an approach in which non-toxic materials are used efficiently and repeatedly considering every step of the whole life cycle of a product or a service, underlining the usage of raw materials during the entire cycle. In the literature, circular design has been conceptualized as a framework by scholars and organizations within differing scales (de Los Rios & Charnley, 2017; den Hollander et al., 2017; Ellen MacArthur Foundation & IDEO, n.d.; Lewandowski, 2016; Mestre & Cooper, 2017; Moreno et al., 2016). Due to the CTC-based nature of the approach, all the studies put material selection at the forefront, and there are forthcoming aspects of circular design considering materials. Included below are the outcomes of a taxonomic analysis of related literature by

Moreno et al. (2016), covering the most prominent materials and design recommendations when designing for circularity:

- Design with living systems in mind.
- Design with the consideration of value in a broader sense.
- Design with the appreciation of tests and prototypes.
- Design with the awareness of the material resource.
- Design while being practice oriented.

2.3.3 Biophilic Design

Erich Fromm coins ‘biophilia’ as the harmonious relationship between humans and the natural environment (Fromm, 1964). It was later defined by Wilson (1984, p.1) in their book *Biophilia* as *“…the innate tendency to focus on life and lifelike processes.”* On biophilic design, after the initial description by Kellert and Wilson (1993), Kellert et al. (2008) broadened the term, underlining the dependency of the well-being of humans on the well-being of the natural environment and the need for increased inclusion within man-made artefacts by providing a didactic narrative primarily for architectural design (AD). Despite being defined or discussed dominantly from the AD perspective, biophilic design is one of the primer concepts in which living organisms are considered as a part of man-made artefacts (S. R. Kellert et al., 2008). Kellert et al. (2008) accept that biomimicry is one of the critical concepts that biophilic design feeds on and underline the importance of biomimicry in achieving biophilic designs. A prominent part of the biophilic design in terms of AD is the dominance of the human-centred approach, which is apparent while designing with natural systems since it is conceptualized with human well-being as a prominent driver (Browning & Ryan, 2020; S. Kellert & Calabrese, 2015; S. R. Kellert et al., 2008).

Due to the conceptualization of the term being carried out mainly for AD, biophilic design is scarcely researched when the issue is handled from an industrial design or product scale. Browning and Ryan (2020) feature product designs in their book, however, with the examples they give, the overall picture stays within textural and visual-based applications. They state: "*Biophilic arts and craftsmanship proffer an enhanced sensory experience - through light, texture, density, radiant temperature and visual complexity - in a way that is not as easily attainable or practical at a larger spatial scale*" (Browning & Ryan, 2020, pp.62-63). Another scholar, Wolfs (2015, p.78), defines biophilic design as *"…through the principles of biomimicry and biomorphism, biophilic design goes one step further by encouraging a symbiotic collaboration with living organisms within industrial products,", going on to give* examples that under the terms of this thesis would be considered mainly as biodesign. Also, the similarity of definition to Myer's (2012) definition of biodesign shows that at the product scale, biophilic design is not well-defined and instead is used interchangeably with biodesign.

In comparison with AD, biophilic design has remained a comparatively 'unpopular category in industrial design, where biodesign is used as the primary notion for product-level applications in which living organisms are directly involved in the design process/outcomes. However, from a contrasting perspective, Myer's book (2012) includes examples from AD as well as product designs, blurring the lines between biophilic design and biodesign further. Also, due to the scale of artefacts, both biophilic design and biodesign differ in definition. Moreover, as biotechnology became a major paradigm, it was easier to adopt such a change for industrial design compared to AD, due to the relatively small size of industrial design outcomes. Therefore, despite being defined for the same designs, whilst biodesign embraced the changes that biotechnology brings, the biophilic design stayed within the notion of integrating livingness in spaces and being inspired by nature for the mutual well-being of the environment and humans, regardless of biotechnology.

2.4 Designing with Living Organisms

By late 1997, the advancements in biotechnology and synthetic biology were accelerating. As the disciplines became widely recognized among people, it drew the attention of artists such as Eduardo Kac and led to the coining of a new term called bio-art (Decia, 1997). Also, simultaneously with these developments, in the 2000s, the design discipline had its turning point; questions about conventional design practice arose, and new roles were emerging (Norman, 2005; Press & Cooper, 2003; Sanders, 2002; Sanders & Stappers, 2008; Sanders, 2008). As biotechnology and material science developed and became more widespread, they collectively constituted a territory that designers could tackle; designers were becoming more interdisciplinary and open to collaborations, which sparked the seeds of unconventional interdisciplinary approaches (Cogdell, 2011).

After a decade, such collaborations between biologists and designers gave birth to the emerging discipline named ‘biodesign’. It is often referred to as the creation of designed artefacts where the livingness of an organism is an essential factor of the design (Myers, 2012). Biodesign is a co-creation practice of artefacts that occurs between living organisms and humans, where the human possesses the guide, and the living organism possesses the guidee roles. Despite becoming a design paradigm, biodesign has its roots in biofabrication, and it is still integrated and dependent on biotechnological developments (Melkozernov & Sorensen, 2021). On the other hand, the processes, and methods that designers have brought, bring new ways of integrating biological systems into everyday life.

Synthetic biology is defined as the use of molecular biology to engineer living cells to alter their behaviour of them (Cameron et al., 2014). As one of the reasons to make biodesign emerge in the first place, synthetic biology developments are prominent drivers in biodesign. Since looking at nature to embody the behaviour of the organisms is the starting point of the design practices around living materials, the research and development in synthetic biology are stimulating the advancements in biodesign. Therefore, such progress allows us to draw a picture of Biofutures for humans' everyday environment. Although synthetic biology is widespread in the fields such as medical appliances and energy production (Cameron et al., 2014), the widespread of the field regarding design practices is yet to happen. However, as featured in *Augmented Biology* by Camere and Karana (2018b, p.572) (see Section 2.4.1.2), there are design efforts in which synthetic biology is directly included in the process (e.g., Vespers III by Smith et al., 2020). Nevertheless, as synthetic biology becomes more integrated with the design of artefacts through the growing number of interdisciplinary collaborations, future design possibilities seem yet to be discovered.

Like prior design fields involving biology (biomimicry, CTC), biodesign can be categorized under DfS approaches. However, like biophilic design, which remains an overlooked part of sustainability so far (Kayıhan, 2018), biodesign is not widely researched in terms of DfS, making it an 'outlier' member of DfS studies. Despite interrelated and mutualistic progress of these approaches, biodesign assesses livingness as an essential component of the design process by reinterpreting livingness in a different manner, differing from taking nature as a source of inspiration, closing the loop, or integrating nature. In this issue, Myers (2012) states, *"unlike biomimicry, cradle-to-cradle, and the popular but frustratingly vague 'green design,' biodesign refers specifically to the incorporation of living organisms or ecosystems as essential components, enhancing the function of the finished work"* (p.8). Apart from biological systems (e.g., algae, fungi, bacteria, plants) being organic, easily biodegradable, and most importantly, requiring little input energy owing to their own energy mechanisms based on metabolism, the feeding elements for living organisms within a design are chosen from renewable resources (Camere & Karana, 2018a; Lelivelt et al., 2015). Moreover, most of the commercial applications of biodesign and design research based on the approach show that the issue of sustainability is one of the most prominent drivers for designers to study biodesign (D'Olivo & Karana, 2021).

With regard to the ethics of biodesign specifically, not been much has been researched; however, it can be stated that, within that area, the ethical sensitisation of biodesign is developing in two separate ways. First is research and applications that propose replacements to our conventional products, which are produced by using conventional materials that are significantly more harmful to nature due to their processes or resources, such as leather, plastics, etc. (Holt et al., 2012; Karana et al., 2018; Lelivelt et al., 2015; Robertson, 2020). Regarding the utilitarian perspective, despite environmental benefits, Montana-Hoyos and Fiorentino (2016) argue that adopting the word 'utilization' of the living is an act of exploitation when living entities are used merely for human consumption and application regardless of DfS strategies. In line with this argument, a second approach emerges: the possibilities of cohabiting with e living organisms, such as in Ginsberg and Chieza's (2018) article for alternative biological futures where humans do not merely utilize living organisms but rather exist with them in a symbiotic relationship, instead of solely using them for consumption and having the livingness terminated after the usage is complete. However, based on the commercial applications and research in the literature on designing with living organisms, the ethical questioning of *what a material is* and *where being a material ends and livingness starts* is still valid (Armstrong, 2022).

Another notable aspect behind the intention to design with living organisms is the novel experience and application possibilities that the living organisms bring. As discussed earlier in the paper, MX is an emerging field in which materials evoke different cognitive reflections for an individual (Camere & Karana, 2017, 2018b; Karana et al., 2010), and MDD is a practice-oriented, material-focused design approach that aims for the best MX (Karana, Barati, et al., 2015). When evaluated within the notions of those concepts, biodesign can offer a diverse range of new interpretations of the experiential levels (see Section 2.1.3) for the user as the final utilizer and for the designer who seeks and evaluates the experiential levels. Based on their interviews with professionals who are designing with living organisms, Camere and Karana (2018a) found out that, apart from sustainability, the unpredictable nature of the act - due to the creatures' own ways of doing things - creates a unique way of applying tools and methods during the design process and pushes the designers to adapt to changes. Consequently, these adaptations and the experimental nature of the design act open up the possibility of innovative material and design outcomes, resulting in novel material and product experiences. In addition to that, when the outcome results in a biofabrication of new material or hybridization of materials with the living organism (see Section 2.1.4), the act of biodesign can be considered a DIY materials practice because the designer's own invention obtains the material outcome and it is a versatile co-design act between the organism and designer in which the designer alters the exploration process based on the needs of the organism (Camere & Karana, 2017).

In the book by Myers (2012), biodesign is defined regardless of the scale of the living organism, ranging from microorganisms (e.g., fungi, algae, bacteria) to plants and even to humans, and is illustrated with diverse examples varying from the product scale to the architectural scale. The diverse scales of the living organisms themselves bring freedom of working regardless of boundaries, yet it causes a vagueness and results in uncertainty in terms of internalization of the topic for novice researchers. Karana et al. (2020) provide an implicit diversification is for when livingness takes place or is encountered, based on product (development/usage) phases. They imply the division of the notion of designing with living organisms into two interrelated parts. First, material biofabrication as biodesign, where often microorganisms are being reproduced for the direct embodiment of materials into products through chemical reactions using either by-products of organisms or the organism itself, such as growing mycelium, fermenting yeast, cellulose production by bacteria and silk production by silkworms, etc. These processes are considered biodesign, but in most cases, after the intended reactions take place and the material production is carried out, the cell division of microorganisms is often stopped when the material embodiment is obtained: it becomes a 'once-upon-a-time living' material. Second, sustaining the livingness of the organism through to the use phase of the artefact, by creating co-habitation possibilities through products (Karana et al., 2020). This time, the outcome is not solely material or a material composite but rather a collective usage of conventional materials and an organism, in which the conventional materials create a habitat for organisms to thrive. These two biodesign classifications require deeper investigation and examples, based on product development/usage phases in which livingness takes place or is encountered.

I. Approach 1 - material biofabrication as biodesign. It is comparatively the older approach where the livingness takes place during the fabrication phase with the purpose of obtaining material(s).

II. Approach 2 - living artefact as biodesign. It is the newer approach where livingness is prolonged to the use phase with the purpose of discovering co-habitation possibilities, and the outcome is often common usage of material(s) and organisms.

2.4.1 Livingness Approach I - Material Biofabrication as Biodesign

Some of the earliest biodesign examples are BioCouture by Suzanne Lee (2010), the Bio Design book by Myers (2012), in which several biodesign examples are present, and Alive: New Design Frontiers exhibition that consists of biodesign examples curated by Carole Collet (Collet, 2013). Also, the concept of new material ecology by Oxman (2010) highlighted the use of biological processes to fabricate objects. Despite mainly being conceptual, the early examples above sparked the interest of designers and showed an alternative path that designers can be part of and apply their designerly ways of thinking. Now, a decade later from these conceptual projects, it is possible to see an abundance of developing commercial examples of biofabrication projects with diverse microorganisms: mycelium applications from the companies such as Modern Meadow, Ecovative, Mogu, MycoWorks, Biofabricate, and Bolt Threads; bacterial applications from Modern Meadow and BioMason; and algae applications from AlgiKnit, Living Ink and Algix.

The examples given are composed of by-products of the microorganisms or the organisms themselves founded and designed with the aid of biotechnological developments. But material biofabrication goes beyond that when the scale of the organisms becomes larger. To comprehend this point, it is important to make a differentiation between ‘old bio-based material’ and ‘new bio-based material’; moreover, the close relationship between bio-based materials and biodesign should be clarified. Since the earlier ages of humankind, homo sapiens have been designing and using animal and plant-based products. These examples range from tool-shaped bones (Hallett et al., 2021) to wooden structures (Rybníček et al., 2020) and leather products (Pinhasi et al., 2010). However, today such conventional applications of wood, leather, or bones fall into the bio-based material category, but they are not referred to in contemporary discussions or research as biodesign and/or bio-designed products. (Oxman, 2010) highlights the relationship between the fabrication of materials, ecology, and sustainability by proposing using novel technologies to transform materials' fabrication into biofabrication. Also, on the relationship between humans and nonhuman organisms, Ingold (2012, p.431) strengthens the theory of new material ecology:

> *“The way to bring them together again is to reverse the assimilation of living nonhuman organisms to pseudoartifacts, by raising artifacts to the status of things that, similarly to organisms, both grow and are grown. To do this, however, requires a change of focus, from the ‘objectness’ of things to the material flows and formative processes wherein they come into being. It means to think of making as a process of growth, or ontogenesis.”*

Based on these statements, the old guise of fabrication of materials can be revised, and the related terms upgraded accordingly. Such an upgrade in perspective does not merely underline the utilization of materials; instead, it emphasizes the extraction or obtaining of materials and how these materials are purposed to create distinct characteristics for biodesign. Comparing two examples would make the issue clearer. The Silk Pavilion by MIT Mediated Matter Group is often referred to as a bio-based material and outcome of a biodesign activity (Camere & Karana, 2018a). In contrast, a product made by using a conventional silk production method - involving killing the dormant silkworm in its cocoon - is not within the sphere of biodesign. In line with this, bio-based materials are used interchangeably with biodesign, although the livingness takes place neither during the fabrication nor prolonged to the use phase; instead, livingness takes place before the fabrication phase. Especially when raw materials are obtained from larger organisms such as plants and animals or derived from their genetic information, if there is no harm done to the organism, the act of producing bio-based materials from raw materials is referred to as biodesign (e.g., QMilk, AMSilk). On this issue, an analysis study by Esat and Ahmed-Kristensen (2018) to classify biodesign applications shows that a few applications that are considered biodesigns use materials derived from 'once living' organisms such as cellulose and milk protein. Daniel Grushkin, the founder and director of Biodesign Challenge, states that defining biodesign as the incorporation of design and biotechnology, and leaving the term fuzzy, allowed designers to be more creative (Grushkin, 2021). Therefore, material biofabrication is carried out with organisms that differ in scale and can be fabricated by a variety of by-products of the organisms, organic waste, or directly from the organism itself (see Figure 2.10).

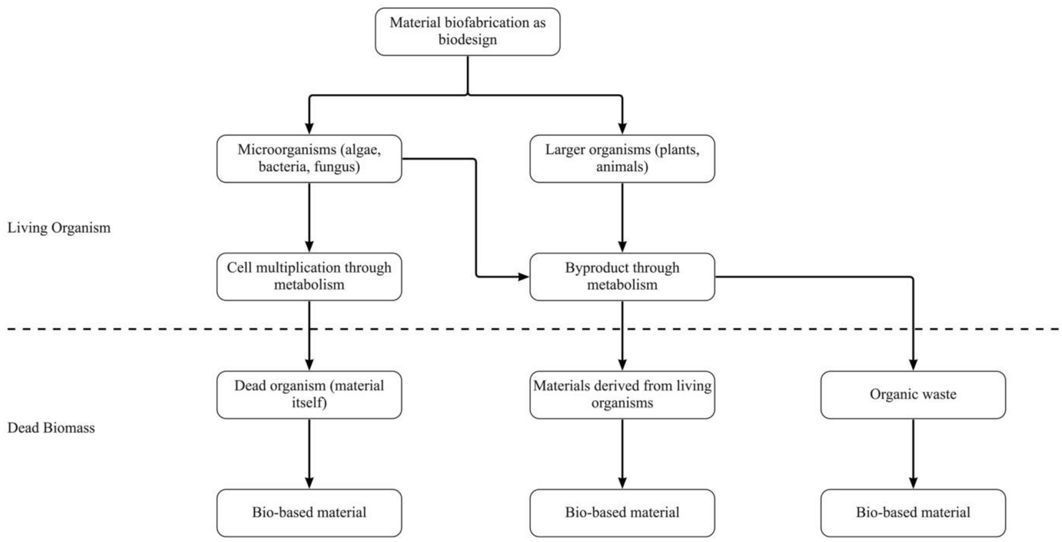


Figure 2.10 Classes of Material Biofabrication as Biodesign (Adapted from Esat & Ahmed-Kristensen, 2018)

DfS research, and more specifically, LCA and CTC within DfS, are two of the most prominent factors driving the involvement of living organisms in material fabrication in the first place (Camere & Karana, 2018a; de Pauw et al., 2015). On sustainable biodesign and participating as a competitor group supervisor in the Biodesign Challenge within this notion, Cogdell (2019, p.24) states: "*I therefore define 'sustainable biodesign' using the lens and tools of life-cycle assessment with an important goal of achieving closed-loop design…".* Within the LCA perspective, biofabricated materials can be examined (but not limited to) two main phases of product life: fabrication and disposal. Regarding raw material obtainment, compared to biofabrication of materials by organisms, conventional raw materials take significantly more time to produce (Camere & Karana, 2017). Moreover, biologically produced materials do not require complex processes to obtain and do not release toxic compounds during their creation (Kırdök et al., 2019). In line with that, a study comparing mycelium bio-composites to conventional insulation materials (expanded polystyrene) shows that mycelium composites do not just perform better but also produce less CO2 and are cheaper to produce (Robertson, 2020). In another similar study, LCA of mycelium hemp shives-based bio-composite as building bricks shows a reduction in most categories (acidification, climate change, water scarcity, and smog) compared to conventional bricks (facing, sand lime, and concrete bricks) yet does increase eutrophication and land use (Stelzer et al., 2021). The studies on mycelium are comparatively widespread since the organism is more studied and commercialized; however, every living organism needs certain growing conditions, which highlights the necessity for research and material assessments focused on particular organisms.

Another aspect of sustainability and LCA regarding material biofabrication as biodesign is the disposal stage of such products. Materials that are either grown into products through cell multiplication or obtained by further processing of by-products of living organisms are comparatively easy-to-biodegrade materials (Cogdell, 2019; Robertson, 2020). Biodegradation is the chemical break down of organic components into inorganic minerals such as H2O and CO2 by the metabolisms of microorganisms (Alexander, 1999). Especially in the flow of reintroduction of biological nutrients for the circular economy model (see Figure 2.9), biodegradation's easiness and rapidity stand out as vital features of biodesigned materials. Biodesigned materials stand as a group of suitable materials in which the reintroduction of such nutrients is achieved easily because the composition of the material is derived from organic resources and makes the flow take place in shorter periods of time since organic materials degrade (and sometimes decompose) in more quickly than inorganic components (Velenturf et al., 2019).

Moreover, the reintroduction of organic nutrients is easier than inorganic nutrients within the circular economy model because inorganic components often need further processing and maintenance before reintroduction to earlier stages (recycle, refurbish, redistribute) (Velenturf et al., 2019). Also, compared to inorganic components, which are often processed, the materials (the organism) not requiring processing beyond its original state makes the material even more sustainable (Walker, 2010). Even in the case of processed biodesigned materials, the tremendously long periods for the reformation of inorganic materials and petroleum-based polymers compared to processes that take place within a lifetime of organisms outline a superiority of biodesign in terms of sustainability and LCA (Camere & Karana, 2017).

Using biological metabolisms for material fabrication showed an alternative way of democratizing fabrication processes, as well as novel and sustainable ways of producing objects. In terms of material-focused design approaches such as MX, MDD, and DIY materials, the act of co-design with an organism showed a possibility to create unconventional material proposals along with novel product and material experience potentials through the meaningful application of such materials (Camere & Karana, 2017; Karana et al., 2018). For example, a design with a mycelium-based composite by Davine Blauwhoff as a graduate degree project using MDD where the designer sought enhanced MX compared to other mycelium applications (Karana et al., 2018). Also, fabricating materials from living organisms is positioned as an act of DIY material creation due to the unexpected nature of the process, where the designer adapts the creation process based on the needs of the organism, sometimes requiring the designer to alter or invent their own methods and techniques (Camere & Karana, 2017, 2018a). Rooted in MX, MDD, and DIY materials, to categorize such practices under the notion of biodesign, Camere & Karana (2018a) looked at usage of diverse methods to discover novel material experiences with living organisms. However, the categorization of the scholars does not precisely match the categorizations covered within this thesis, with some examples prolonging livingness to the use phase (the second biodesign approach, to be covered later). Yet, based on the emergence of these categories' periods (which are earlier) and the dominant examples under them, I intend to examine these categories under 'material biofabrication as biodesign.' These categories are growing design, augmented biology, digital biofabrication, and biodesign fiction (Camere & Karana, 2017, 2018a).

2.4.1.1 Growing Design

Growing design is defined as the hands-on novel material creation process where the material is created as the outcome of the designer's collaboration with the living artefact, which is not necessarily genetically modified (Camere & Karana, 2017). It is often considered as a co-design activity where designers guide the living artefact to be grown into desired design outcomes. Some examples have come from: plant bodies, The Gatti Chair by Full Grown UK (Alice Munro & Gavin Munro, 2015); plant roots, Interwoven by Diana Scherer, 2016; a collaboration with bees, The Honeycomb Vase by Tomas Libertiny, 2010; and collaboration with silkworms, Silk Pavilion I and II by MIT Mediated Matter Group (Costa et al., 2018; Oxman et al., 2014) (see Figure 2.11). A further collection of examples come from the guidance of three main types of microorganisms: Bacteria, algae, and fungi (Camere & Karana, 2018a) (see Figure 2.12). The bacteria (often used for the production of cellulosic materials in a symbiotic culture with yeast) and mycelium (the growth process is controlled within the biocomposites based on organic substrates that create nutrients and structure for organisms to grow on) share similar strategies in terms of growing and shaping the material (Camere & Karana, 2018a): The steps in growing and shaping the material are as follows: 1) setting the right conditions for the organism to thrive; 2) growing the organism; 3) deactivating the livingness of the organism and; 4) shaping the final material.

Figure 2.11 A: The Honeycomb Vase by Tomas Libertiny, 2010; B: Silk Pavilion I by MIT Mediated Matter Group (Oxman et al., 2014); C: The Gatti Chair by Full Grown UK (Alice Munro & Gavin Munro, 2015)

A crucial issue concerning growing design is that the practice does not necessarily shape around the growth in its literal meaning. Instead, growth here can also be interpreted as the process of increasing in size in time, especially in cases when the *grown* is not the organism itself but rather the by-product of the living organism. For example, despite having a similar process, cellulose or pigment production by bacteria is an act of by-product fabrication by the metabolism, whilst mycelium growth means cell reproduction and growth in living cells. The matter of by-product is comparatively more observable in the case of larger organisms. For example, shaping beeswax into objects by guiding the bees' behaviour to produce beeswax objects in various shapes and dimensions is a growing design practice. However, the results do not directly imply the growth of bees; instead, it is the growth of the honeycomb where bees inhabit and collectively 'grow' using their by-products (e.g., The Honeycomb Vase by Libertiny, 2010). On the other hand, in terms of growing design, the process of algal materials does not directly suggest growing the organism into products but instead growing and using the organism or by-product of the organism as a raw material for the development of novel materials, in line with the DIY-materials approach (Camere & Karana, 2017).

Examples of commercial applications of mycelium range from leather to acoustic panels, packaging material, and even construction bricks; the bacteria, on the other hand, ranges from natural fabric dyes to biosensors (Camere & Karana, 2017, 2018a; Holt et al., 2012; Karana et al., 2018; Robertson, 2020) (see Figure 2.12). Considering these examples and the professionals who practice biodesign to biofabricate materials, Camere and Karana (2018a) conducted a field study with eight professionals, drawing a picture in which there is a need for reinterpretation of the design discipline regarding production, interdisciplinary approaches, sustainability, and new material ecologies to support practicing growing design.

Figure 2.12 A: Algal materials, Desintegra.me by Margarita Talep, 2017; B: Fungal materials, Mycelium Chair by Eric Klarenbeek, 2013; C: Bacterial materials, BioBomber Jacket of BioCouture by Suzanne Lee, 2011

2.4.1.2 Augmented Biology

Augmented biology stands for the redesign of the organism at the cell level, which necessitates a multidisciplinary approach where designers collaborate with bioengineers (Camere & Karana, 2017). The redesign of the nature and natural systems is the primary driver in this approach, in which the designer works with synthetic biologists and bioengineers to transform the organisms' genetics and to benefit from these genetic modifications by rethinking them as design potentials. However, despite being defined by design scholars for the involvement of a designer in biotechnological processes (Camere & Karana, 2017, 2018a; Karana et al., 2018), the approach does not particularly involve designers in the process. Non-design proficiencies can drive the process, yet the results can have design potentials. For example, using genetically modified bacteria to detect landmine locations using fluorescence is one such intention where the process is driven by bioengineers (Belkin et al., 2017) yet carries further design potential. Apart from that, some examples are directly relevant to the design field. For instance, Bolt Threads, the company that patented Microsilk, a material produced by bioengineered yeast, is a superior thread in terms of performance and sustainability based on the genetic data of spider silk (Widmaier et al., 2018) (see Figure 2.13). As this example shows, since the examples in this category are mainly driven by scientific developments, the designer's involvement is limited to the design phase instead of creating the material. Nevertheless, as design potentials become more apparent for materials development (Barati & Karana, 2019), collaborations across disciplines will surge; hence new augmented biology examples will emerge.

Figure 2.13 Products Produced Using Microsilk (Bolt Threads, n.d), A: Moma Dress by Stella McCartney, 2017; B: Cap of Courage by Best Made Co., n.d.; C: Microsilk Tie by Bolt Threads, 2017

2.4.1.3 Digital Biofabrication

Digital biofabrication is the process in which the organisms are guided and manipulated with computational tools and novel technological advancements such as additive manufacturing and parametric modelling (Camere & Karana, 2017, 2018a). Compared to the previous two approaches, digital biofabrication does not necessarily involve a genetically modified organism (GMO) as in the case of augmented biology. It differs from the growing design by prioritizing technology as an actuator of nature instead of a practice-led approach adopted by growing design (Camere & Karana, 2017). The act of growing (cell multiplication or by-product production) is common in both growing design and digital biofabrication. However, in the case of digital biofabrication, organisms are guided through technology instead of guidance by the designer. In other words, the designer designs the technology which will lead the organism.

The examples within this category vary based on the technology used for the process, and they can be examined based on the purpose behind utilizing technology. First is the usage of technology to create a structural skeleton for organisms: for example, in the Mycelium Chair by Eric Klarenbeek, the designer uses 3D PLA and a straw printed scaffold to create a structure for the mycelium composite to thrive on (Klarenbeek, 2013) and usage of parametrically designed 3D printed PLA beams for plant roots to grow on (J. Zhou et al., 2021). Second is the use of technology to create a habitat and growing environment for the organisms, such as the 3D printed Banyon Eco Wall for plant habitation by BigRep and NOWLAB (Claßen et al., 2019) (see Figure 2.14) and Vespers I, II, and III by the Mediated Matter Group, MIT. The researchers created a habitat with the usage of hybrid technologies for genetically modified bacteria to live in to show the potentials of the bacteria as biosensors (Bader & Oxman, 2016). Third is the manipulation of organisms' behaviour; for example, in Silk Pavilion I and II by Mediated Matter Group, MIT, the material is created to seek the potential of an ecological version of conventional silk production, by guiding the silkworms through creation of a kinetic structure with the help of hybrid computational technologies. This results in silkworms producing silk in a designed shape (Costa et al., 2018; Oxman et al., 2014). Fourth, and last, is using technology to cultivate the organism within different mediums to create hybrid materials, such as BioLogic by Tangible Media Group, MIT, which involves 3D printing of once-living bacterial cells onto designed fabrics to create responsive behaviour for clothing (Yao et al., 2015). It is essential to underline that digital biofabrication is not limited to these categories because it varies and will vary as the fabrication technologies develop.

Figure 2.14 Banyon Eco Wall by BigRep and NOWLAB (Claßen et al., 2019)

2.4.1.4 Speculative Biodesign and Biodesign Fiction

Design fiction was firstly coined by science-fiction author Bruce Sterling when he mentioned the effect of design thinking when shaping their thoughts on their writings

(Sterling, 2005). After the initial coining of the term, Julian Bleecker wrote an article about how the idea of 'design fiction' can be elaborated and used within the design domain by connecting the terms design, science, fact, and fiction (Bleecker, 2009). Since then, the field started to develop and became a design and research approach that can lead people, especially within co-design sessions, to think beyond the normal boundaries and guises of the design profession, such as production, cost, marketing, etc.

In an interview, Sterling (2012) defines design fiction as *"...the deliberate use of diegetic prototypes to suspend disbelief about change,"* giving a scene from the film 2001: A Space Odyssey (Kubrick, 1968) as an example, in which we see a digital 'tablet' that the character uses to watch a video broadcast. In reality, tablets reached commercial success and widespread use a long time later, at the beginning of the 2010s (Bosch, 2012). Elaborating on Sterling's example, two terms should be clarified to grasp a better understanding of what design fiction aims. The first is the diegesis: the world in which the described situations and events take place (Cambridge Dictionary, n.d.); the second is the diegetic (prototype): a real-world (novel) object that is a part of everyday life in the diegesis (Cambridge Dictionary, n.d.). So based on the example, the film's narrative is diegesis, and the tablet used in the movie is a diegetic prototype. In the same interview, Sterling highlights the excellent execution of the prototype and addresses the lawsuit between Apple and Samsung on violating patent rights which Samsung defended, referencing the film 2001: A Space Odyssey, stating that the tablet computer was conceived in 1968 (Potter, 2011) (see Figure 2.11). Being the smallest of the entry points into a diegesis, the diegetic prototype invites people to enter the world of the designed artefact just as any other designed artefact for that world (Coulton et al., 2017a; Pilling et al., 2021).

Figure 2.15 2001: A Space Odyssey (Wigley, 2019, as appeared in Kubrick, 1968)

Apart from the coining of design fiction, Dunne, and Raby (2013) coined speculative design, a broad term beyond critical design, to define speculative methods within the design profession. Speculative design intends to *ask questions through design rather than answering them* by questioning the social aspects of design, human-object relationships, and the prospects thereof. Therefore, design fiction can be assessed as a sub-branch of speculative design in terms of the thinking process and being future-focused, but it is not limited to speculative design in terms of application, since the latter tends to be more based on critique and questioning, sometimes regardless of the future. Design fiction is characterized as imagining possibilities sometime in the future, beyond the here-and-now (Montgomery, n.d.; Near Future Laboratory, 2022). On the other hand, in their book, Dune and Raby mention the close relationship between speculative design and design fiction, underlining the argumentative sides of both approaches towards probable/possible futures (Dunne & Raby, 2013). Montgomery's (n.d.) mapping of the speculative design fields clarifies the positioning of each method (see Figure 2.12).

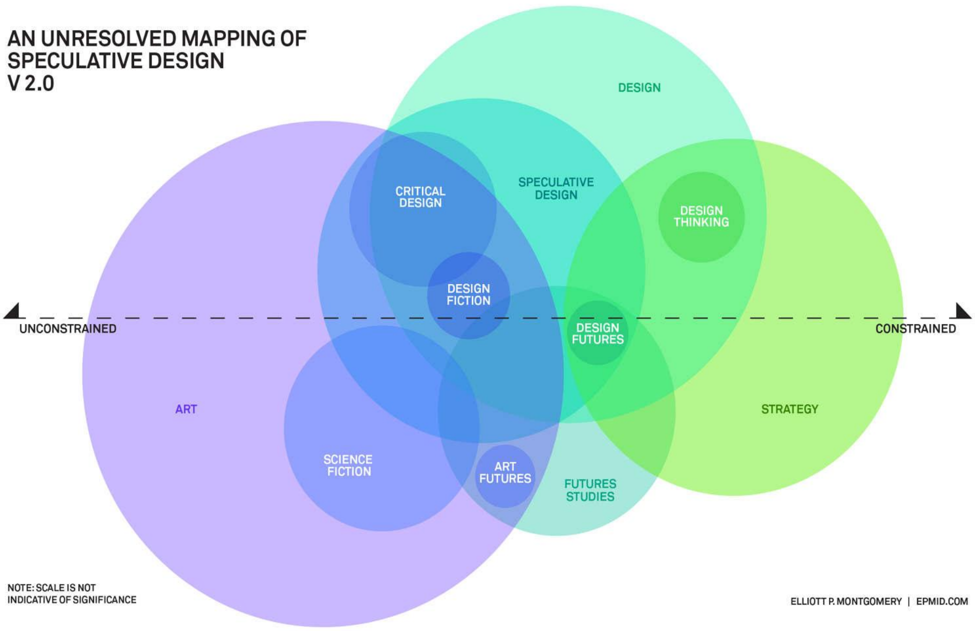


Figure 2.16 An Unresolved Mapping of Speculative Design (Montgomery, n.d.)

By merging speculative design, design fiction, and biodesign, Camere and Karana (2017) coin the term biodesign fiction to define design outcomes based on or around biological entities, which themselves are speculative and can be positioned within the probable futures. The emphasis on 'probable futures' is important: outcomes of biodesign fiction will likely go beyond the current boundaries of design and biotechnology, but equally are not within the realm of fantasy. They are grounded in some realities presented or predicted today. By imagining the future of design, biotechnology, and materials science alongside 'probable futures' within the diegesis, designers can create diegetic prototypes, scenarios, and speculations which are a part of everyday life in imaginative worlds (Camere & Karana, 2017; Ginsberg, 2013). For example, the Mercedes-Benz Biome Concept Car was designed as a diegetic prototype resulting from speculations on the idea of growing a car, and that each individual vehicle would have its unique DNA (Tatti, 2020) (see Figure 2.17).

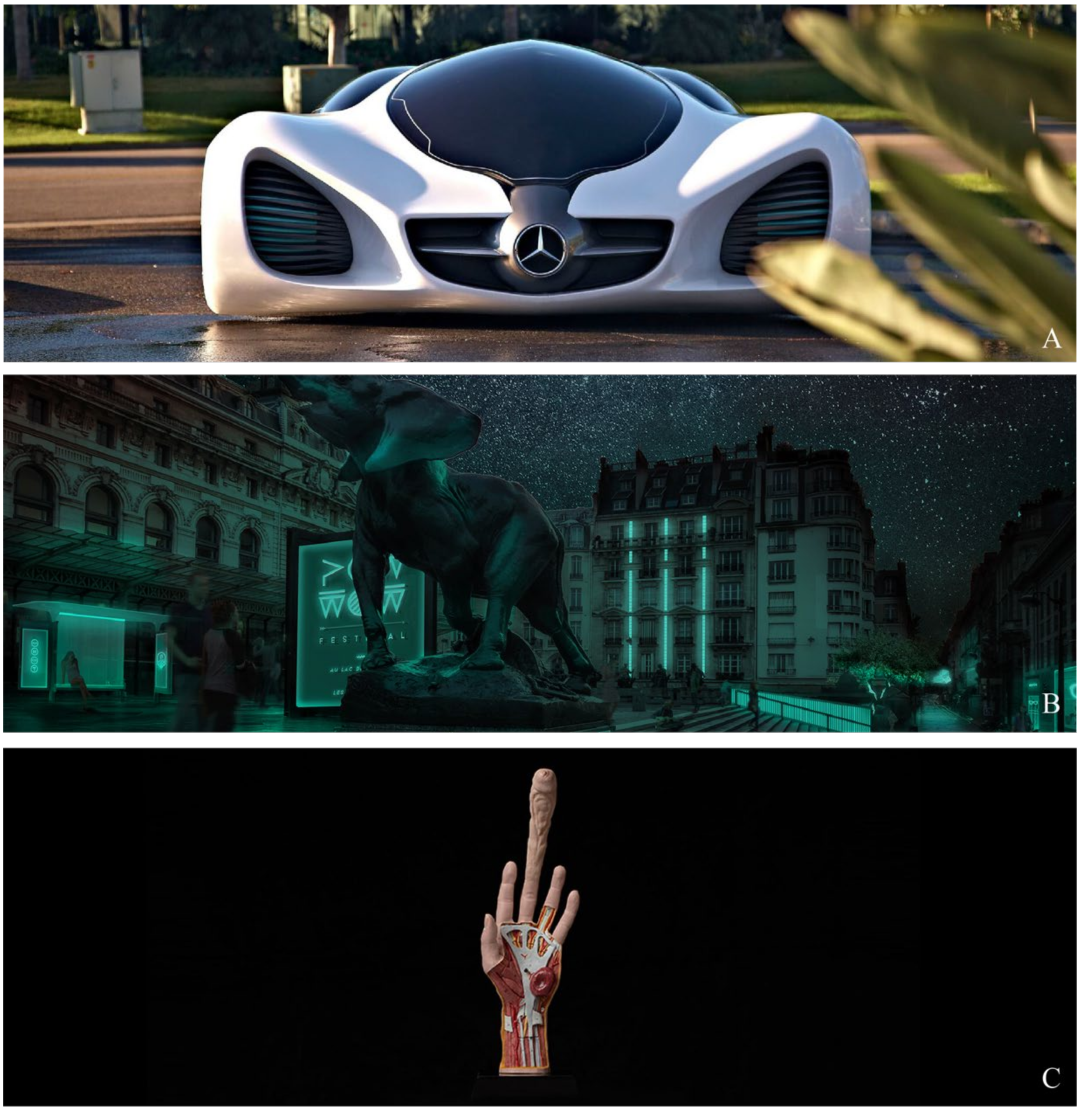


Figure 2.17 A: Biome Concept Car by Mercedes-Benz, 2010 (Tatti, 2020); B: Glowpolis (a city illuminated by bioluminescent microorganisms) by Glowee, 2022; C: Seeding Finger (a finger that would let women become pregnant on their own with the help of a hand-shaped pump) by Koo Hyeonjeong, 2018 (Morby, 2018)

Another example is from Dunne and Raby's book mentioned earlier, *Speculative Everything,* in which designers define four divisions in England based on ideologies that take place in a future scenario. One of them is defined as *"bioliberals,"* stating *"bioliberals live in a world in which the hype of synthetic biology has come true and delivered on its promises."* (Dunne & Raby, 2013, p.180). Apart from individual projects, biodesign fiction is becoming more widespread with other incentives such as competitions, e.g., Biodesign Challenge (https://www.biodesignchallenge.org/), online publications, e.g., Biodesigned (https://www.biodesigned.org/), and workshops (Gough et al., 2021). Since interdisciplinary requirements of biodesign and long development processes of technology makes the process of applied biodesign take longer, the advantage biodesign fiction can bring to design research is to operate outside these practical constraints and promote creativity through diegetic prototype storylines. Therefore, despite being investigated under the comparatively less speculative approach (material biofabrication as biodesign) in this paper, biodesign fiction can go even further than the second approach (living artefact as biodesign) due to its discursive and creative characteristics.

2.4.2 Livingness Approach II - Living Artefact as Biodesign

Differing from material biofabrication, *the living artefact as biodesign* intends to prolong livingness into the use phase of an artefact. In contrast, as the primary driver, the scope of material biofabrication stays within the production of the artefacts, regardless of their final state of livingness (Karana et al., 2020). However, citing Myers (2012) again, livingness might be an indispensable quality of new kinds of artefacts, for example enhancing the function of a final design. Despite being highlighted from a materials innovation perspective relatively recently by Karana et al. (2020), living artefacts have been featured in books (Dunne & Raby, 2013; Myers, 2012, 2015), articles (Barati & Karana, 2019; Cheok et al., 2008; Ginsberg & Chieza, 2018; Karana et al., 2019; Kawakami et al., 2010; Liu et al., 2018; Poupyrev et al., 2012; Seo et al., 2015; Smith et al., 2020; Yao et al., 2015) and exhibitions (Chieza, 2020; Collet, 2013; Telhan et al., 2018). Compared to material biofabrication, the commercialization of the design outcomes into everyday objects is comparatively few for living artefacts, especially if microorganisms are involved due to managing the constraints and sensitivity of the organisms. Therefore, commercial applications, which include larger organisms, i.e., plants and animals, can be found in the market, such as aquaponic farming, which is a type of hydroponic farming that maintains a mutualistic relationship between fish and plants (Somerville et al., 2014) and an ambient light powered through chemical reactions of plants, designed by Ermi van Oers and Plant-e (2016).

It is crucial to clarify that the outcomes are often hybrids of living entities and conventional materials or upgraded/adapted versions of traditional materials, due to the necessity of creating a habitat for the organism to thrive (Karana et al., 2020). Based on this, there are two possibilities to integrate livingness into an artefact so far. First, using the other (conventional) material(s) to create an environment for the artefact or, in other words, achieving a: a) *container* or b) *skeleton* in which the organism does not directly interact with other materials, but rather the materials used around the organism create the boundaries and shape the artefact contained with the organism; or the organism grows on the non-living material making it its skeleton, especially in cases with plants and mycelium. Second, the organism is embedded directly onto the conventional material, making the livingness a *material quality* rather than an *object quality*, especially when a culture of organism is embedded to materials such as fabric.

Three examples of the two different applications help to make the differentiation clearer: Ambio by Teresa van Dongen (2014) is a lighting design that uses bioluminescent bacteria in a container designed for the habitation of the organism; an example in which the roots of oat plants are directed by 3D printed PLA which is shaped into a low stool (Zhou et al., 2021); and lastly, Biogarmentry by Roya Aghighi (2019), in which living algae are embedded onto fabrics making the livingness and changing patterns a material quality (see Figure 2.13).

Figure 2.18 A: 'Container' Approach in Ambio Lamp by Teresa van Dongen, 2014); B: 'Skeleton' Approach in an oat root stool (Zhou et al., 2021); C: 'Embedded' Approach in Biogarmentry by Roya Aghighi, 2019

Ginsberg and Chieza's (2018) article, *Other Biological Futures,* in which the authors question the tendency to merely utilize organisms for our purposes within our current consumption habits, had a profound effect on biodesign research and led others to handle the issue of designing with organisms in a holistic perspective in terms of sustainability and consequently led to the investigation of cohabitation possibilities. So, before the act of design, which is often carried out for solving human problems, the needs of the organisms should be prioritized and investigated, so that cohabitation possibilities can be established. For this purpose, despite particular needs among differentiating organisms, Karana et al. (2020) draw an outline before the design act and investigate the livingness phenomenon in three categories, namely: biological, ecological, and experiential.

As a *biological* phenomenon, Jones, and Jones (2014, p.2 as cited in Karana et al., 2020) define seven common characteristics of all organisms, which are *growth, movement, sensitivity, excretion, reproduction, nutrition,* and *respiration.* Karana et al. (2020, p.40) summarizes the common characteristics by correlating them with the act of design in one sentence; *"…if artefacts possess livingness as a quality, they will have the unique ability to: grow, metabolize, respond to external stimuli, reproduce, move and respire, and, ultimately, adapt to their environment."* In line with that, the mentioned characteristics are common for all organisms, and human beings are one such example. Therefore, compared to non-living artefacts, living artefacts may evoke empathy in relation to an increment in perceived consciousness (Chapman, 2012). From the product design perspective, Chapman (2012) defines empathy as a rare response to designed products, yet a crucial factor in people's apportioning of value to a product and, therefore, of importance if lengthened product lifespans are to be achieved. Moreover, one of the DfS strategies, Design for Sustainable Behaviour (DfSB) (Lilley, 2009) integrates the notion of empathy and *empathic design* (Leonard & Rayport, 1997) to grasp a better understanding of the user's perspective (Daae & Boks, 2015). DfSB also emphasizes the role of empathy in communication between product and user as an empowering addition (Daae et al., 2018). And lastly, Wilson (1984) and Kellert & Wilson (1993) underline the importance of the appearance of the living within human artefacts for the well-being of humans. When these theories are further assessed together in terms of living artefacts, the biological processes of the organisms may offer benefits in terms of DfS: 1) increasing the perception of empathy resulting in longer lifespans; 2) triggering sustainable behaviour change with care and empathy; 3) increasing human well-being and mutual living.

Karana et al. (2020) mention livingness as an *ecological* phenomenon by drawing attention to the responsive behaviour of organisms to their surrounding environment and the relationships between the members of the same species and those that are different. The authors state: *"…livingness as a design quality requires from an ecological standpoint the careful crafting of cohabitation, intra/interspecies interaction, and their relation to other non-living entities (e.g., soil or computational artefacts) within an ecosystem."* (Karana et al., 2020, p.41). The symbiotic relationship within an ecosystem does relate to the appearance of the living artefact in the everyday human environment, where humans create a symbiotic relationship with the artefact. Yet, symbiosis can take different forms: first, mutualism, where both organisms benefit; second, commensalism, where one benefits and the other is neither harmed nor benefited; third, parasitism, where one benefits and the other gets harmed; fourth, predation where one feeds on the other; and lastly, competition where two organisms compete for various reasons (National Geographic Society, 2022). The earlier human-made artefacts, which are fabricated through the involvement of organisms and were primarily created for human utilization and aimed for human purposes (see Figure 2.14), do signify a parasitic relationship where only humans benefit; however, the attitude must change to include other organisms as living beings rather than simply accepting them as resources (Ginsberg & Chieza, 2018; Keune, 2021; Westerlaken, 2020).

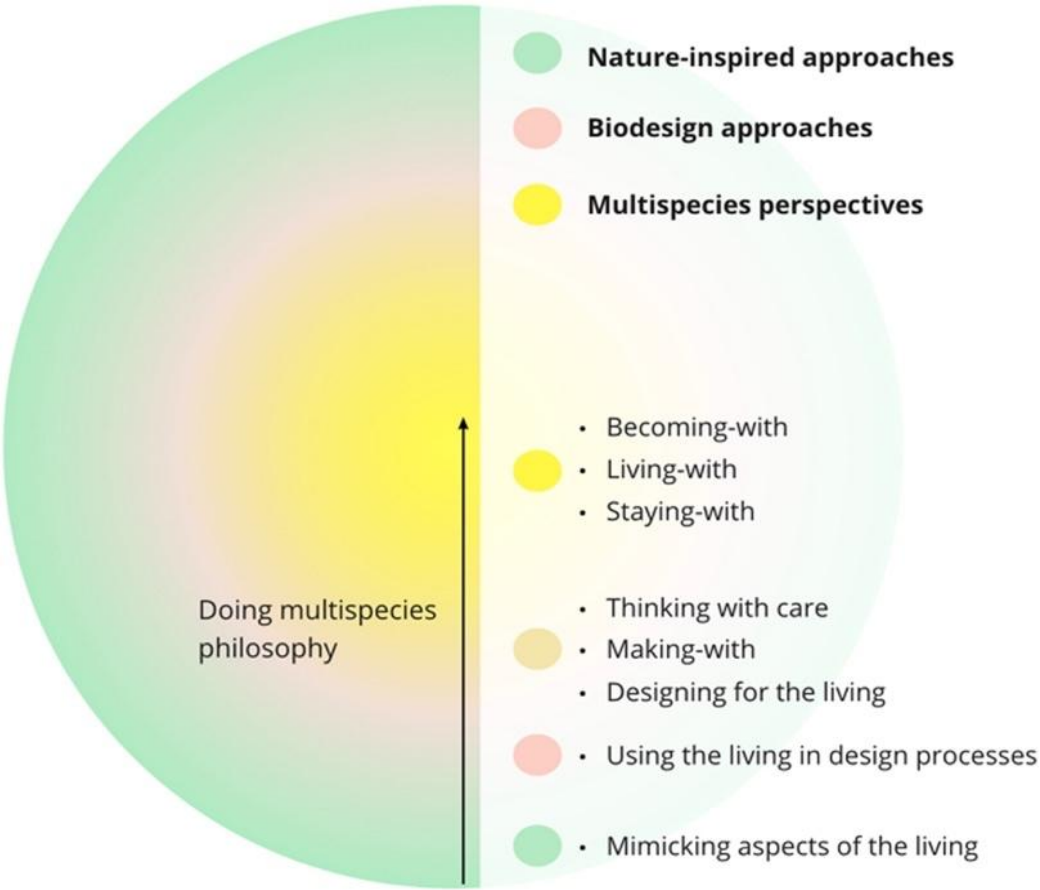


Figure 2.19 A Graphical Representation of the Conceptual Framework that Relates Nature Inspired Approaches with Biodesign and Multispecies Perspectives (Keune, 2021, p.26)

Anthropocentrism is an essential term to position humans in various ecologies. It is defined as a human-centric approach that advocates the utilization of everything else for the sake of humans (Kopnina et al., 2018). The anthropocentric approach has had a profound effect on the design field (Forlano, 2017), but a transformation can be seen among design scholars, especially in shifting from an ecology of human to human-centric approaches (Bardzell et al., 2021; Coulton & Lindley, 2019; Forlano, 2017; Hupkes & Hedman, 2022; Zhou et al., 2022). On the ecology of the living, living artefacts, and humans, Ginsberg & Chieza (2018) state that bio-futures will not be radically different if the anthropocentric approach persists; therefore, a shift should take place concerning the human-centred approach.

Lastly, scholars investigate livingness as an *experiential* phenomenon stating: *"…livingness as a design quality from an experiential standpoint requires the careful crafting of material qualities by taking into account the changes in a living organism over time and the specific actions, they might elicit from people due to their livingness."* (Karana et al., 2020, p.42). Going back to MX, due to novel experiential possibilities of the living artefacts, the keywords to measure different levels of MX, namely sensorial (hard, matte, etc.), affective (love, disgust, etc.), interpretive (sexy, elegant, etc.), and performative (e.g., make us do *something*) (Camere & Karana, 2018b; Giaccardi & Karana, 2015) do not comprehensively cover the unique experiences of living artefacts, hence making the experiential characterization of the material toolkit (Camere & Karana, 2018b) insufficient because of the novel material affordances and materials experiences unique to organisms (D'Olivo & Karana, 2021). Also, in an analysis based on biodesign companies' web communications, a need to better transmit the experiential qualities of living materials is underlined (D'Olivo & Karana, 2021). In response, in a recent study, Ertürkan et al. (2022, pp.14-15) devised a new vocabulary for living artefacts, compiled under five different themes.

- *"The origin of living materials"*
- *"The making of living materials"*
- *"The agency and autonomy of living materials"*

- *“Temporality of living materials”*
- *“The impact of living materials”*

From the experiential standpoint, two themes stand out as the most prominent: the *agency and autonomy of living materials* and the *temporality of living materials*. As one of the words in the vocabulary (Ertürkan et al., 2022), *responsiveness* is one of the seven qualities which are common to all organisms (Jones & Jones, 2014). The responsive behaviour of the material can make communication possible between the user and the artefact and offer novel interaction possibilities in terms of MX and, more specifically, in terms of the performative level of the materials (Barati et al., 2017, 2018, 2019). Based on that, the responsiveness of organisms can propose new ways of interacting with artefacts not just regarding usability (e.g., response to motion such as bioluminescent algae) but also maintenance (e.g., response to environmental change such as algae as bioindicators). Other aspects connected to organism temporality that makes living artefacts unique are the *unpredictability* and *intelligence* of the organisms. As presented in the ‘material biofabrication as biodesign’ section, the livingness is often not easy to control due to organisms’ own agency, which allows the process to deliver a surprise experience (Camere & Karana, 2017, 2018a). In material biofabrication, such quality might be limited to the design phase, which shapes designers’ methods and ways of doing; however, when the livingness is prolonged to the use phase of artefacts, the user becomes the one who faces the surprise factor. Surprise is listed as an important factor that triggers imagination for emotional durability in terms of product longevity, so the surprise factor might create a sense of wonder, allowing the user to discover the artefact further (Haines-Gadd et al., 2018). Surprise is also listed as an emotion evoked by a material at the affective level (Camere & Karana, 2018b). Due to the temporality and livingness of the organisms, the surprise factor becomes a prolonged and kinetic experiential characteristic for living artefacts which is continually experienced rather than being static and limited to the initial interaction with a material (Karana et al., 2020).

The creation of living artefacts is directly related to the MDD method, especially regarding the material tinkering process. The handling of the livingness as a different phenomenon carries undiscovered material potentials, which makes them need further investigation. Hence transforming the *material tinkering* process of MDD to more like understanding the organism process, which may offer meaningful -and in this case, unique- MX when embodied in products. Taking MDD as a starting point and considering the need for a new design framework (Karana et al., 2019), Karana et al. (2020) propose a framework which takes the three aspects (biological, ecological, and experiential) as a starting point and demonstrates with examples answers to the question, 'what might be possible if everyday objects were alive?' To answer the question, the authors suggest three principles for designing living artefacts: 1) living aesthetics, 2) mutualistic care, and 3) habitabilities.

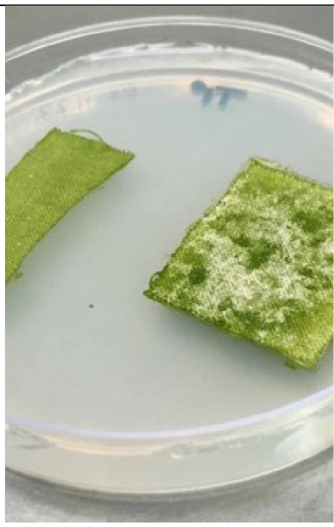
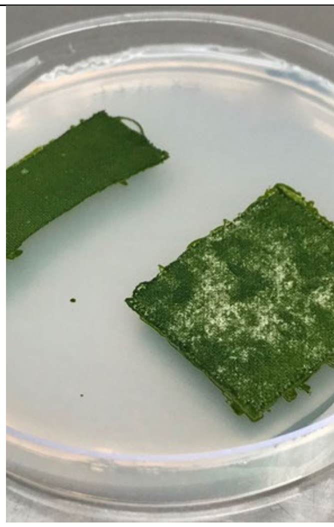
2.4.2.1 Living Aesthetics

Based on growth and reproduction, the authors position living aesthetics as *"…the way humans experience the type, degree, and duration of change in a living artefact over time (e.g., immediate or gradual changes in colour, form, or function)",* stating that the word aesthetics is used to express the 'change' rather than aesthetics per se (Karana et al., 2020, p.45). As well as the *type of change*, *the duration and degree of change* are crucial points under the notion of living aesthetics and such changes are the indication of organisms' (hence artefacts') current state to understand whether they are healthy or not, which makes the execution quite important to increase the lifetime of the artefacts (Karana et al., 2020). A comparison of examples can help to illustrate the different types of changes (see Table 2.1 and Table 2.2).

Table 2.1 Type of Change First Row: MycoComposite and AirMycelium by Ecovative, n.d.; Second Row: Vespers III by MIT Mediated Matter Group (Smith et al., 2020)

Type of change The first row illustrates the different outcomes with different material properties. In the left picture, mycelium's growth is manipulated to have strength, whereas, in the right image, the same mycelium is grown to be foam-like for different applications. https://www.ecovative.com/pages/mycocomposite https://www.ecovative.com/pages/airmycelium		
In the second row, the masks are filled with genetically modified organisms and the organisms produce different pigments that changes the colour of the masks based on the wearer. https://oxman.com/projects/vespers-iii		

Table 2.2 Degree and Duration of Change First Row: Biogarmentry by Roya Aghighi, 2019; Second Row: Ambio Lamp by Teresa van Dongen, 2014

Degree and duration of change In the first row, living photosynthetic algae are embedded in the fabric and the change time (growth) is within days. The algae grow on the material, and as they grow, they make the fabric greener. https://www.royaaghighi.com/biogarmentry.html		
Within the container, bioluminescent bacteria are present. Without motion, the picture on the left defines the state of the lamp; but when the light (consequently the bacteria) is exposed to movement, the bacteria give an instant reaction and glow. http://www.teresavandongen.com/Ambio		

2.4.2.2 Mutualistic Care

Mutualistic care stands for the notion of the creation of mutualistic relationships between humans and artefacts, necessitated by the presence of livingness. Such a relationship is proposed to be based on humans embracing a custodian role for the well-being of the artefact due to particular requirements that every organism needs (e.g., nutrients, sunlight, darkness, oxygen, etc.), and in return for the care the artefact provides functional or experiential benefits (Karana et al., 2020). In order to keep the artefact healthy and long-lasting, a consideration of mutualistic care when designing with living materials is stated as a must-to-consider factor as it will affect the artefact's performance and well-being (Karana et al., 2020). Adding to the examples in the previous section, the Breathing Shoe (see Figure 2.15) illustrates a symbiotic relationship between humans and the living artefact (PUMA et al., 2018). The shoe is designed to adapt to the wearer’s foot sweat pattern; the sweaty and heated parts of the foot activate the microorganisms, and the microorganisms start to digest the material creating a unique shoe with unique ventilation openness for the wearer. The most heated and sweaty parts become the thinnest parts, degrading based on the foot heat map.

Figure 2.20 Breathing Shoe (PUMA et al., 2018)

2.4.2.3 Habitabilities

Karana et al., (2020) define two habitats for the living artefacts: 1) the first habitat (design habitat) is defined as the medium where organisms are the inhabitants (a container or a structure for the organisms); 2) the second habitat (use habitat) defines the environment in which the living artefact is positioned. Initially, the design of the first habitat could be carried out by identifying the particular needs of the organism: first, to design the overall composition of the containing structure, the possible maintenance interactions with the organism, and the ease of maintenance of the artefact should be considered; second, an understanding of the necessary nutrients and the biological processes within the habitat are needed for the organism to keep it alive. For example, with the Ambio lamp by Teresa van Dongen (2014), the containing structure (a glass tube) is designed to contain the necessary nutrients and the particular composition of the environment (artificial seawater in this case) and to ease the maintenance of such a composition (e.g., changing the composition if necessary, adding nutrients, discarding by-products, etc.). When the design of the first habitat is carried out within a closed container, the artefact allows a 'closed interaction' with the user. In contrast, in the example of Biogarmentry by Roya Aghighi (2019), algae are embedded in a textile (first habitat), making livingness a material quality, which can be named as an artefact that allows an 'open interaction' with the user.

Apart from the design habitat, for the second (use) habitat, Karana et al. (2020, p.49) state: *"…the living artefact is envisaged to be situated within a context which includes both living and non-living entities."* Elaborating on the Ambio lamp example, the use habitat is designed by considering the interaction with humans (which are inhabitants of the second habitat) because the microorganisms contained within the structure need a motion from an outside factor to glow in the dark. On the other hand, elaborating on the Biogarmentry, the other external factors which are not present in the first habitat (the textile) that is required for wellbeing/ usage/

maintenance of the artefact (e.g., sunlight for photosynthetic microalgae cells, oxygen, CO_2) must be afforded in the use habitat.

Table 2.3 Left: Ambio Lamp (Teresa van Dongen, 2014); Right: Biogarmentry (Roya Aghighi, 2019)

A - The design habitat: On the left, it is designed like a close 'petri dish' system (close interaction), whereas on the right, it is embedded in the textile making it a material quality (open interaction).
B - The use habitat: On the left, the use habitat is designed and envisioned to allow interaction with the user so that bioluminescence can be initiated. On the right, the use habitat is the sunlit environment so the algae on the textile can thrive.
C - The user (inhabitant of the use habitat): The consideration of the user-artefact relationship is necessary for the design of the use.

2.5 Summary

The literature review chapter presented the literature regarding design, materials and experiences and their relationship with organisms when combined under biodesign.

A novel understanding of materials has been discovered after presenting a change in the scope of industrial design. Furthermore, it is underlined that such a change did not occur only for the usage of conventional materials but also occurred for the creation of novel materials. It is noted that, correlatively, the experiences around materials, hence products, evolved when designers are involved in the material creation process. One of the reasons for such involvement, sustainability related to materials and design (regarding DfS and SDGs), is presented.

After presenting these topics, the chapter focused on an emerging paradigm of biodesign. Initially, the understanding of ‘bio-’ is discussed within the fieldwork of design as a whole and then within industrial design deeper, trying to explain the different terms and precedent approaches related to the combination of design, materials, and biology. Later, it progressed as diving into the investigation of biodesign more precisely, and two different approaches emerged in the paradigm explained. The first is named ‘Livingness Approach I - Material Biofabrication as Biodesign’, in which livingness is conceptualised to create novel materials benefiting from their metabolism. The second one is named ‘Livingness Approach II - Material Biofabrication as Biodesign’, in which the livingness is aimed to be prolonged to the use phase of artefacts by creating a mutual relationship between humans and organisms.

Despite emerging in the first livingness approach, biodesign fiction is not deeply investigated after the emergence of the second approach. Specifically, after Karana et al.’s (2020) conceptualising livingness article, the future of living materials is not explored when the notion of ‘cohabitation’ of humans and organisms is involved. Therefore, combining the scholars’ positioning of biodesign fiction and conceptualising materials together, I will investigate the future of cohabitation possibilities rather than what biodesign fiction is positioned for, which is often the future of living materials and design regardless of cohabitation and interaction possibilities when humans are cohabitated with living materials in the future. In doing so, I aim to investigate the human perspectives regarding the future of living materials as well as the cohabitation possibilities. In the following chapters, I will explain what I have done to achieve my goal, which consists of three consecutive chapters: A sensitisation process, a design process and a workshop process.

CHAPTER 3

METHODOLOGY

This thesis aims to investigate the future of designing with living artefacts using design fiction methods, by exploring the possible speculative experiential potentials, cohabitation possibilities, practices, and attitudes when we switch from inert products and infrastructure to biologically alive replacements. I planned to carry out this research step by step to achieve such an aim. So, the main study was designed after a sensitisation process, and the empirical research method is affected by the sensitisation process and the respective literature. In this chapter, I will explain the research methodology from a broader perspective to draw an outline. The respective chapters will present specific details of my sensitisation process and my empirical data collection through a workshop and its analysis.

3.1 Research Design Overview

The research has been designed to be completed in three phases. In the first phase, a field trip to the Netherlands is organized as a preliminary preparation stage to internalize and personally contextualize the biodesign literature. During the field trip, I had the chance to visit a biodesign lab and held discussions with biodesign researchers. I have compiled my sensitisation notes chronologically in a field notes format. Despite mentioning the respective literature for the first phase of the research, the research design was not finalized at the time of the conduct, and since it was an activity that I carried out mostly for personal development and sensitisation purposes, the data I presented reflects my thoughts and observations. Nevertheless, the main reason behind including research methods literature related to field trip information-gathering and sensitising concepts is that it helped shape my visit and guided me to reflect on my thoughts better.

Subsequent to my field trip and taking into account key findings from the literature, I have designed a generative workshop in which participants could speculate specifically on biodesign without staying within the boundaries of design limitations. The carrying out of the workshop was considered as the second phase of the research, with the analysis comprising the third phase. The workshop has been applied with the attendance of nine participants to explore future scenarios regarding experiential potentials, cohabitation possibilities, practices, and attitudes when people switch to living with living artefacts.

3.2 Research Approaches

I used qualitative data collection methods to generate empirical data to complete the research. The reason behind this is that the study requires a more profound understanding of people's perspectives, thoughts, and experiences (Matthews & Ross, 2010; Ritchie et al., 2013; Robson & McCartan, 2016), especially in the case of benefiting from people's creativity during the workshop. Therefore, I have adopted a "*flexible research design strategy,*" which is used to define qualitative methods in which the research is being shaped by the researcher during the process, and the data obtained are non-numerical (Robson & McCartan, 2016, p.145). Holistically, I have adopted an action research approach. More specifically, for phase I, I pursued a combination of Rapid Ethnography and Grounded Theory approaches. The workshop for phase 2 asked participants to generate design scenarios and proposals, which were used by me as 'vehicles' to help answer research questions. Accordingly, the phase was informed by Research through Design (RTD), which itself may be regarded as a particular form of Action Research.

3.2.1 Ontological and Epistemological Positioning

By using qualitative data collection methods, this research adopts an interpretative approach which is often considered to be based on two thoughts (Levers, 2013):

- **Relativist ontology***:* Reality is understood individually based on the perspectives and interpretation of the world; therefore, the possibilities of realities are endless (Denzin & Lincoln, 2008).
- **Subjectivist epistemology:** It is not possible to separate the researcher from the researched subject since knowledge cannot be isolated from people (Denzin & Lincoln, 2008).

Inductive reasoning is defined as the generation of a theory based on the data rather than using the data for proof or testing of a proposed theory, and there is a dynamic relationship between the data and the hypothesis (Ritchie et al., 2013). Qualitative research is often carried out with an inductive approach to theory-generation (Robson & McCartan, 2016). However, there is not a purely inductive approach since the researcher starts with an assumption and prior knowledge regarding a subject (Ritchie et al., 2013), and therefore rapidly adopts tentative positions regarding possible theories and explanations.

3.2.2 Participatory Action Research

To collect empirical data, I have positioned participatory action research at the core of my thesis. On participatory action research, Ritchie et al. (2013, p.67) state: *"…research as a collaboration between researchers and the population that is the focus of research, with a core aim being to enact positive change for those involved in the research process."* The authors especially underline the noteworthiness of the approach regarding creative data-collection methods in qualitative research, citing McNiff's (2008) definition of art-based research (Ritchie et al., 2013). McNiff (2008) defines art-based research as using creative tools for the data collection regardless of the subject and drawing attention to a clear distinction from research about art. A workshop (generative session) as a data collection method can be considered a generative data collection method applied under the participatory action research approach, since the data collection is derived with creative tools and needs the researcher's involvement to prompt participants to take action towards the generation and communication of ideas connected to the workshop theme.

Collaboration with the research participants is the main critical point of action research (Robson & McCartan, 2016), even starting from the research design (Ritchie et al., 2013). Since the participants' involvement could shape the overall design of the research and even the research question, it is considered a flexible design strategy (Robson & McCartan, 2016). However, the participants' involvement may be problematic if the subjects are involved in all stages of the research since the control of the study becomes limited in terms of designing the path for data collection for answering the research question (Robson & McCartan, 2016). Because of that, I have limited the involvement of the participants to the empirical data collection phase, but due to cumulative data collection (phase I and phase II), the participation of the researched subjects remained prominent.

3.3 Research Ethics

In the first phase of the research, the primary purpose of the visit was to gain personal knowledge regarding practicing biodesign and working with living materials. These are carried out as a private activity and compiled in a journal. Nevertheless, I would like to clarify that all my field trip activities were permitted by an invitation letter; hence they were consensual and the purposes of my visit were made clear in advance.

The second phase of the research led to the primary original data set for this research. To protect confidentiality and anonymity, I prepared a consent form and had the forms signed by the workshop participants at the time of their arrival (see Appendix A, Informed Consent Form). The definition of the research, research purposes, possible usage of data, the method to collect the data, and contacts are thoroughly explained. Ethical clearance from the METU ethics committee was obtained (No. 0453-ODTUIAEK-2022) (see Appendix B, Ethical Approval Letter).

3.4 Phase I: Biodesign Sensitisation

To observe organisms directly and gain more expert knowledge regarding living materials, my thesis supervisor and I arranged an instructional week in the Netherlands by communicating with Prof.Dr. Elvin Karana. The main reason behind including this phase in the research was twofold. First, the practical side of biodesign was unfamiliar to me, and I had inadequate knowledge that was limited to theory. In practice, it requires new ways of doing and a different set of knowledge (Karana et al., 2019). Second, because of the novelty of the biodesign field, the facilities and practicing experts I could reach were limited. Still, I needed a comparatively comprehensive understanding of working with living materials to carry out a workshop confidently and effectively with participants. So, instead of being conducted as a research study, the visit was arranged in an informal manner, with the specific of improving my knowledge of working with living materials. Therefore, I named this process the *field trip,* so my experiences during the trip were on how others work with living materials and how I understood and interpreted those people's experiences.

Overall, the data that emerged from the field trip can be considered anecdotal evidence. It is based on personal experience and observation collected without a systematic approach and does not qualify as scientific evidence (Lilienfeld et al., 2003). Consequently, there are objections in methodology literature regarding including anecdotal evidence and personal experience as scientific knowledge ("Anecdotal Evidence", 2022), but I had no such intention to use my findings as scientific knowledge. **Instead, I intended to become personally sensitive to biodesign and living materials concepts and methods of study.** On this, Lilienfeld et al. (2003) state (p.9): *"Testimonial and anecdotal evidence can be quite useful in the early stages of scientific investigation. Nevertheless, such evidence is almost* *always much more helpful in the context of discovery (i.e., hypothesis generation) than in the context of justification."* Moreover, I believe that for full transparency regarding my research process, it is important to convey my journey as it happened. Herein, with the goal of hypothesis generation, combining Sensitising Concepts with Rapid Ethnography is an effective combination for anecdotal evidence collection within the scope of my study.

3.4.1 Sensitising Concepts

Grounded theory is one of the qualitative approaches carried out in social sciences research, wherein the core principle is to obtain data with an inductive logic and to analyse the received data simultaneously to produce theory out of the data instead of proving theory with data (Bowen, 2006).

Sensitising concepts are explained as concepts to be studied and understood to facilitate success in taking a Grounded theory approach to data collection and analysis. Blumer (1954) separates concepts into two, which are 1) definitive concepts and 2) sensitising concepts. On definitive concepts, Blumer states: *"...refers precisely to what is common to a class of objects, by the aid of a clear definition in terms of attributes or fixed bench marks."* (p.7). On the other hand, Blumer defines sensitising concepts as follows: "*A sensitizing concept lacks such specification of attributes or bench marks and consequently it does not enable the user to move directly to the instance and its relevant content. Instead, it gives the user a general sense of reference and guidance in approaching empirical instances."* (p.7) The vagueness of the definition may result in a sensitising concept being labelled as a definitive concept; however, it needs to be questioned whether there are other reasons for this to take place (Blumer, 1954). From an empirical standpoint, the main reason for a concept to be sensitising and not definitive is the particular character of a subject in a specific nature of a context (Blumer, 1954).

Within the focus of this research, biodesign is approached as a sensitising concept to be able to plan a meaningful workshop experience in the area of living materials. The vagueness of the term, which I have argued in the literature chapter, has helped me, in this case, to understand subject-dependent interpretations and compare what I interpret as a researcher. Also, as mentioned in Section 2.4.1 on Biodesign Challenge, Grushkin (2021) states that the vagueness of the term may lead outcomes of research to be varied rather than similar. Therefore, a clear connection can be made between approaching the term as a sensitising concept and the variety of design outcomes that can be expected from a Biodesign Challenge. Parallelly, the sensitisation process outlines a valuable function in design research and in developing design projects regarding how to design (Waern et al., 2020; Zimmerman et al., 2010).

3.4.2 Field Trip as a Rapid Ethnography Method

Ethnography is a widely used method in qualitative research (Denzin & Lincoln, 2008; Ritchie et al., 2013; Robson & McCartan, 2016) and in the field of design to help designers to grasp a better understanding of complex relationships between humans and artefacts (Wasson, 2000). However, it is often time-intensive for researchers to collect and analyse the data (Ritchie et al., 2013). Millen (2000) highlights that given the time constraints, *rapid* ethnography stands out as a prominent method for researchers to collect data and analyse in shorter periods, stating: *"In this approach, fieldworkers undertook short, focused studies to rapidly gain an understanding of the work setting"* (p.280). Since my field study was limited to one week in duration, a rapid ethnography approach was helpful to grasp a preliminary understanding of biodesign, while observing researchers working with living materials and discussing their experiences with them. Based on personal experience and research, Millen (2000) defines two critical aspects of rapid ethnography, which are parallel to my study:

- Focusing and narrowing the research interest in terms of activities.
- Using multiple interactive techniques to gain valuable knowledge.

Despite advocating the involvement of multiple researchers simultaneously for richer results (Millen, 2000), it was not possible for my field trip; therefore, I conducted the journey solo, by documenting the process through pictures and note taking.

Field trips comprise specific-purpose travel and actions around a journey that takes place within a stakeholder's local working environment. The primary advantage of field trips is the potential to gain knowledge regarding the experiences within that environment. As mentioned before, the rapid ethnography approach provides a space to generate valuable data for researchers to immerse themselves in the environment for a short period (Eden et al., 2019). Given these qualities, the similarities in conduct between a field trip and the rapid ethnography approach illustrate that taking a relatively brief field trip to a working environment can be considered as an implementation of rapid ethnography, allowing a researcher to sensitise concepts within the focus of research. Nevertheless, Eden et al. (2019) underline that field trips are beneficial when they are conducted as a preliminary sensitisation stage, as a part of a more comprehensive research study, stating: *"...when field trips are used as a method, it is important to apply the same qualitative tools and techniques in the same rigorous and systematic manner as when they are implemented in long-term studies"* (pp.2-3). Parallelly, in the same article, the authors define four circumstances suitable for a field trip, before more comprehensive empirical research is carried out (Eden et al., 2019):

- When there is a limited amount of information on the subject and setting.
- When a researcher intends to understand the specific experiences of the stakeholders.
- When a researcher intends to understand the personal opinions of the stakeholders.

- When the actions and performances of a specific task are within the focus of the research.

3.4.3 Information Gathering During the Field Trip

Initially, for the preliminary phase, the information during my field trip were based on my personal experiences and insights and I have collected these in a notebook. The way I took these notes in this research is based on what I observed during my field trip. However, these observations are not constructed in an established observation setting. Instead, the field notes I took were as part of my daily life interactions during the field trip, along with self-reflections on what I observed. Yet, since my intention was not to conduct an observation per se, the processes of how data were generated during the field trip was not a primary driver in the research's first phase, neither video nor audio recordings were taken through the process, but pictures were taken to label important events during the trip. Eden et al., (2019) list field notes as a way to create insights based on experiences shaped around observations and conversations. Hence, I considered that taking simple field notes and memos to record my observations and discussions would be sufficient for a personal sensitisation process.

3.5 Phases II and III: Design Fiction Workshop

For the main phase of this research, I have designed and carried out a workshop to discover new kinds of practices that may surround objects in which livingness is material quality. To achieve such an aim, I decided to take a generative approach. As explained earlier, data collection from a generative workshop can be evaluated under the action research approach, bringing with it the creativity, beliefs, opinions, experiences, etc. of designers or other creative individuals. These qualities are common to much qualitative research. Within the design research domain, the positioning of a workshop with an embedded creative/generative session can be referred to as a form of RTD. This is essentially because of the involvement of a creative design process as part of the data gathering and analysis strategy.

3.5.1 Research Through Design

RTD is made popular through the writings of Frayling (1993). In his article, within the scope of art and design, three categories of research are proposed: a) *research into art and design*, b) *research for art and design,* and c) *research through art and design* (p.5). In similar work, design researcher Bruce Archer (1995) questioned the relationship between research practice and creative practice and defined three approaches by which creative practice could form a part of research practice, namely: a) *research about practice*, b) *research for the purposes of practice,* and c) *research through practice* (p.7). Despite minor differences, both Frayling and Archer create a similar outline for design research, and the categories are considered to be still valid while conducting design research. However, decades later these terms are still evolving, and the relationship between research and design remains open to arguments (Zimmerman & Forlizzi, 2014). Still, as in any design education program, research already plays an indispensable role in generating a starting point and evaluation tool for design projects, and there is a strong connection between the two (Stappers & Giaccardi, 2017).

For RTD, a relatively new - but not so different - definition is made by Zimmerman & Forlizzi (2014, p.167): *"Research through Design (RtD) is an approach to conducting scholarly research that employs the methods, practices, and processes of design practice with the intention of generating new knowledge."* This thesis accepts this general view of RTD. During the research, there are two periods in which designing was central to the research process. The first was during the conception and development of the workshop. The workshop's design was affected by what I personally researched, and my intention to design directed me towards what to explore. Moreover, as a researcher utilizing flexible qualitative methods, the design of the research methodology and the approaches I planned to follow were affected by the design process. In short, this process of wandering around these two ends (research and design) is a clear illustration of the RTD process. Second, the workshop also fits within the definitions of RTD because the scenarios and designs (prototypes) that participants generated (co-designed) served the purpose of research entities, synonymous to data generated using other research methods. Prototypes are an essential part of RTD because they serve as a tool to do research, or a tool to be evaluated through research, or are directly an outcome of research (Stappers & Giaccardi, 2017).

3.5.2 Research Through Design Fiction

Putting the emphasis on prototypes, research through design fiction (RTDF) is a research approach where research through design is allied to design fiction concepts, especially the notion of creating prototypes that are intended to fit to a given diegesis, which is constructed with the future in mind (Blythe, 2014; Coulton et al., 2017; Lindley, 2015). The prototypes, however, do not necessarily have to take the form of 3D physical objects, and instead can be narratives, scenarios, films, drawings, etc., which represent a provocative or thought-provoking entrance point to the diegesis (Coulton et al., 2017; Markussen & Knutz, 2013; Pilling et al., 2021). As discussed in the previous section, prototypes can adopt various roles when taking a RTD approach (Stappers & Giaccardi, 2017), but within the focus of this particular research, they are planned to form a cluster of generated empirical data to be further analysed and discussed. Including other design research approaches, Lindley (2015) summarizes the inclusion of design fiction in the research process, which was found to be directly relevant to the process that I carried out. Accordingly, I sorted Lindley's (2015) approach (see Figure 3.1) (and mine in brackets): 1) creating research inputs by designing (design of the workshop); 2) RTDF - research through design fiction (application of the workshop); 3) design fiction prototypes to generate new knowledge (analysis of the workshop). In the same article, Lindley (2015) also differentiates RTD from RTDF, underlining the importance of the latter for qualitative research, since the focus is on people's insights and visions rather than end products, stating: *"... because design fictions are primarily aimed at producing insights, it is arguable that any design fiction practice is by definition a research practice too."* (p.4)

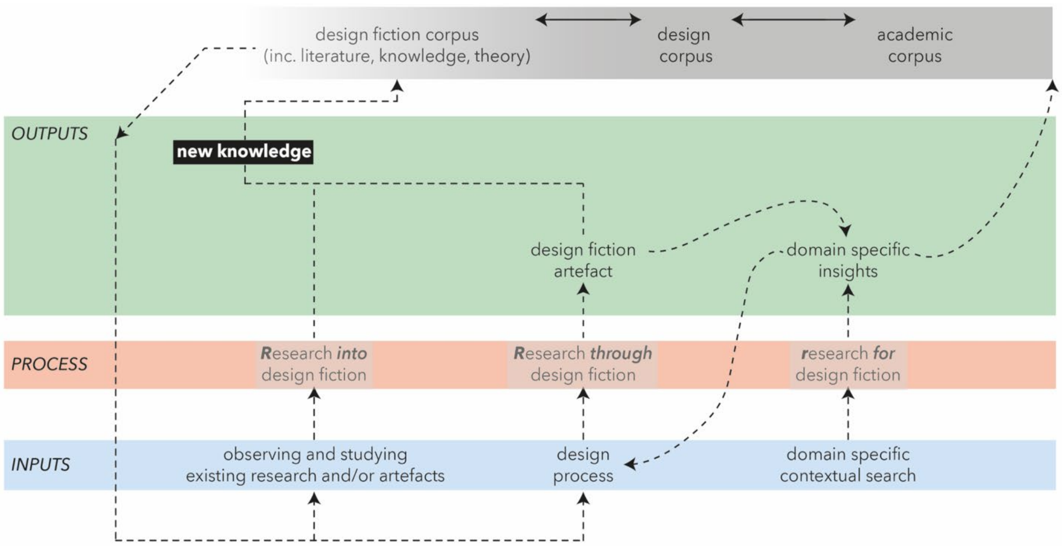


Figure 3.1 Interrelations Between Different Categories of Design Fiction Research (Lindley, 2015, p.4)

Blythe (2014) underlines the benefit of using design fiction as a tool for research through design (e.g., allowing a certain level of ambiguity by creating discursive spaces resulting in speculative results), stating: *"The use of design fiction helped identify weak ideas without discarding them and also helped identify whether particular prototypes would be likely to answer research questions"* (p.710). Using design fiction for my study goes parallel to that reasoning because of certain requirements: 1) a level of ambiguity was needed for my study to let participants freely think, since the researched subject is essentially what people think of, act around and how they experience biodesign in principle rather than creating or testing a specific biodesign artefact; and 2) the novelty of the biodesign makes not just recruitment but also workshop application processes hard if a more straightforward MDD method was pursued considering the novelty of skillsets. So, the discussive nature of design fiction has helped direct me towards feasible research in the field of biodesign and livingness, in line with my personal experience and the practical constraint of not having access to facilities dedicated to growing and looking after living materials.

RTD seems promising as an effective research approach for studying new kinds of materials and their relationship with design. In established material-focused design approaches such as MDD and DIY Materials, research studies are carried out mostly *through* the application of a material to a given design or directly by the design of the material itself, making the main focus the design and materialization action (Karana et al., 2015; Rognoli et al., 2015). Therefore, I name these kinds of processes as 'research through material design.' However, because of the reasons listed above, instead of focusing directly on material, I aimed to merge future biomaterials with future scenarios, reaching a 'research through biodesign fiction' approach. As I presented in Chapter 2.4.1.4, many biodesign fiction examples exist, but usually outside the context of empirical research for scientific studies. A few examples exist: first, in a study conducted by Ertürkan et al. (2022), design fiction is used as a research method to discover novel material futures and alternative possibilities. The second is a doctoral dissertation by Çağlar (2021) in which the researcher implements design fiction methodology and biodesign as part of their research.

3.5.3 Data Collection and Data Recording

Various qualitative data collection methods were planned for adoption in the research. The main emerged from the first phase is based on my inferences during the field trip. For the second phase, I designed my primary data collection method as a workshop, and within the workshop, I planned to adopt the participant observation role to collect data using data collection sheets. Apart from that, the data collection sheets are designed to be distributed to participants adopting a *participant as* *observer role* to whom I planned to assign a person each group for real-time data collection to support the voice and video recordings since it would not be possible to follow each group in detail on my own. Ultimately, I also planned and designed the workshop to obtain data from the participants' act of producing creative outcomes such as scenarios, materials, and designs; meaning that the creative outcomes of the workshop themselves are a part of data collection. Overall, for the generative session, I planned to collect four datasets: 1) My workshop observations collected using data collection sheets, 2) reporters' observations collected using data sheets within each group, 3) participants' reflections and the creative outcomes produced during the workshop, 4) voice and video recordings from the workshop.

3.5.3.1 Field Notes

Field notes are a fundamental and well-established data collection method in the qualitative research approach (Ritchie et al., 2013). They can provide the necessary generated data to be further analysed by the researcher during the research process and can be a complementary data collection method when used with other primary data collection methods, such as interviews, focus groups, observations, etc. (Robson & McCartan, 2016). Field notes during observations are considered to be inseparable from the researcher's view and influenced by the subjective thoughts of the researcher. Hence, the data is literally 'generated' by the observer rather than naturally occurring (Ritchie et al., 2013), which goes hand to hand with an interpretivist approach. On the other hand, regarding pairing data recording methods with field notes, Ritchie et al. (2013) highlight the importance of recording audio - and video if useful - while taking field notes of a meeting or encounter, underlining the value of details and verbatim in communication between people.

For the second phase of the research, I created semi-structured field notes along with video and audio recordings. The rationale for the inclusion of video recordings was because in studies involving group discussions, video recordings could help capture the interactions between people (Ritchie et al., 2013). Because the verbatim transcription, video, and sound recording analysis are time-intensive, especially for a creative method involving more than five participants, to ease the data analysis, the field notes used during the generative session were semi-structured (see Appendix C). Using semi-structured field notes, the researcher can focus on the primary datasets they seek to obtain within the workshop, rather than getting lost in the multi-levelled, divergent, and sometimes confusing structure of participants' communications.

3.5.3.2 Participant Observation

Observation is one of the main methods in qualitative research that yields high potential, especially in understanding complex interactions between people and the individual actions people carry out. In research methodology literature, various ways exist to categorize observational techniques, based on mainly three qualities of an observation. First, the role of the researcher in an observational method; second, the level of structure of the observation setting; and third, what and/or whom to observe and parallelly, how to optimally collect data (Ritchie et al., 2013; Robson & McCartan, 2016). Another aspect is that observation is a subjective act, from which the researcher's (observer's) point of view inevitably influences the data collection and data analysis. Addressing the issue of biases, especially during the conduct of the method, Ritchie et al. (2013) highlight the importance of 'awareness of biases' before carrying out research, and refraining from it by acknowledging the *self-biases* which depends on an individual basis. Besides biases, transparency toward participants (overt observation) and data discretion is of utmost importance while implementing an ethical approach to observational techniques (Ritchie et al., 2013).

I will describe my workshop study based on the three categories listed above. The role I have adopted is the *observer as participant* role, which is defined by Ritchie et al. (2013): *"…involves observing as unobtrusively as possible, engaging in the setting to some extent but usually only for short periods of time"* (p.320). By being the facilitator of the workshop, my only intention was to guide people and inform them regarding the milestones through the generative session, rather than actively participating as an active member during the workshop. This is because my involvement as an active participant would result in over-interpretive data since I already had an influence on the design of the workshop - I already guided participants through the process. Second, I define my second step as a semi-structured one. The workshop involves a *research through design* process, with the workshop design setting certain frames and boundaries during the workshop; however, being a creative session, a workshop (especially a speculative one) needs some space for participants to generate ideas without being overly constrained. Third, the main research question of the study demands that the most valuable data comes primarily from (i) what participants have created during the generative session (directly, and because of analysing the generative session outcomes), (ii) their cognitive behaviour and logic behind the creative process, and (iii) their social behaviour and interactions. Therefore, based on that hierarchy, the data collection and recording methods are designed accordingly. Hence, the field note sheet is structured. The field notes and video recordings complement the main recordings of data (i.e., the design outcomes).

3.5.3.3 Using Group Reporters

Considering the time spent and the number of participants, it is not easy to record and collect data in a workshop setting, which means that the researcher has to adopt a stenographer role in a workshop setting accompanied by recordings (Ørngreen & Levinsen, 2017). The dynamic interactions and technical needs occurring in a workshop setting, such as making sure people follow the required steps, providing necessary equipment, dealing with the environmental factors etc., make a workshop setting a relatively complex approach for a researcher to collect data. Despite my presence, and that of the recording devices, small details may be overseen in a workshop setting while groups are working. Because of that, I planned to use one group reporter assigned per group in the workshop as it can be beneficial to capture things that I possibly missed, due to an absence at the time of the occurrence of data, some kind of disruption, and/or a technical issue that might take place for recording devices.

On focus groups, which is another research method involving numerous participants at the same time, Krueger and Casey (2002) state: *"Because there is so much going on in the focus group, the moderator often is not able to lead the discussion, observe, and take notes at the same time. The assistant helps with the arrangements, takes careful field notes, and assists with the analysis"* (p.13). I considered each workshop group as a different focus group. Therefore, an *assistant moderator* was assigned to each group. However, to refrain the workshop from becoming a merely observational setting disrupting the creative process by the feeling of being observed, group reporters were planned to be recruited. They would be later assigned with the *participant as observer* role, in close contact with other participants (Ritchie et al., 2013) and a part of the creative process. This is in contrast to my own role, which was *observer as participant*, as explained earlier. To support the coherence of the data collected by the group reporters and to refrain from biased data collection, I designed data collection sheets (see Appendix C), which are planned to be introduced to the reporters of each group prior to the workshop.

3.5.3.4 Designing as a Data Collection Method

The design process can be considered as a data collection method, and the design outcome can be evaluated as data. Adopting the notion of *doing design is doing research* on producing knowledge out of design by researchers, Stappers & Giaccardi (2017, p.7) state: *"...in every design project they (can) learn something: about the users' lives, about a piece of technology, about a new mechanism or form, about how to create an effective prototype, or about how to evaluate it under challenging circumstances of limited budget, time, and means"* despite acknowledging the fact that research process of every design does not convey any information. Nevertheless, in the workshop where the participants' design process is observed and recorded, design outcomes produced in such a setting have the potential to carry information. Apart from the research design, the workshop is designed so that participants produce information relevant to the research aim and suited to answering the research question presented in Chapter 5.

Adding to Stappers and Giaccardi's statement on the issue, by adopting *research through design fiction*, I have aimed to produce knowledge by analysing the design outcomes complementary to the analysis of the field notes of both my and reporters' recordings. With the potential to ask questions rather than answer them (Dunne & Raby, 2013), speculative approaches to design, such as design fiction, are developed to probe further discourse (Bleecker, 2009). That has the potential to make data (designs or prototypes) that can be interpreted in numerous ways. Prototypes in design fiction are not limited to 3D objects but can include narratives, scenarios, and interactions (Blythe, 2014; Coulton et al., 2017). Such prototypes do not carry the intention to be materialised; instead, they aim to produce insights for further discourse regarding the concept as much as design fiction itself (Lindley, 2015). Hence, the creative process carried out by participants during the workshop represents the data collection method, while the design outcomes represent the data to be further analysed. To answer the research question, the creative output and discussions in the workshop step out as the most crucial dataset in this research.

3.5.4 Sampling and Population of The Workshop

From a holistic perspective, the sampling process is carried out under the general category of *non-probability sampling,* which is often used in qualitative studies to represent the distinct features belonging to a particular population (Ritchie et al., 2013). The particular population I indented to recruit is characterised by their skillsets and abilities. However, the act of design or ability to design is not particular to any group (in fact, it is common to all humans), but because of the limitations such as recruitment time, identifying potential participants etc., the main criteria in the non-probability sampling process was mainly 1) a higher education degree and 2) a relevant profession. That being the case, homogeneous purposive, snowball and convenience sampling (at a certain level) are used complementarily.

The sampling process for the workshop was planned as two stages. The initial sampling process was carried out by identifying design professionals (who received materials in design education) for the workshop. Within the scope of this research, *design professionals* stand for the industrial designers, architects, and interior architects who obtained at least a bachelor's degree in relevant design fields and/or master's degree in design (regardless of their current professions). This sampling process is featured as *purposive sampling,* where the participants are chosen based on a specific purpose (Ritchie et al., 2013) (in this case, proficiency in the design process and necessary skillsets to produce design outcomes in a time-intensive setting). Since the type of higher education degree is the only criterion sought for the recruitment process and is common to all, it represents a homogeneous sampling (Ritchie et al., 2013) in which all participants are designers and participate in the workshop with their designer identities. However, I am aware that it is debatable whether higher education degrees create designers or design abilities, especially if graduates are not practising the profession.

Nevertheless, since measuring such abilities and recruiting after doing so would be too overbearing for this thesis, the sampling process also included convenience sampling, characterised by purely the availability of the participants (Ritchie et al., 2013) at a certain level (especially in terms of age and social closeness). Early recruits were asked to convey the information regarding the research to friends who have at least the university degrees mentioned. This method is mentioned as *snowball sampling*, where the researcher asks participants to actively contribute to the recruitment process, after which the researcher can recruit further participants in case a sufficient level of diversity of participants has not been achieved (Ritchie et al., 2013).

The secondary sampling process is carried out amongst the participants, who chose the reporters (assistant moderators) for the workshop - this time considering their current profession based on a similar principle. Since I am working as a research assistant at a university in the industrial design department as I am writing this section, it was convenient and purposive to nominate other design researchers as the reporters assigned to each group based on their abilities (acknowledging biases). Consequently, the sampling process is completed after sampling another group from the initial population (see Figure 3.2).

Since the sampling process is organised and the prospective participants are reached based on the criteria mentioned above, there was neither an elimination nor selection process to recruit participants. The criteria set for the sampling (design graduates, most of them are full-time working) made the recruitment process very hard since the participant convenience was limited. Therefore, although the invitation has been sent to many prospective participants (at least sixty people), only twelve responded, clarifying their availability. Even on the day of the workshop (October 15, Saturday), three did not show up for various reasons. That being the case, the selection of participants stayed limited with having a bachelor's degree in design without any further elimination process based on knowledge or experience in the respective subjects (design fiction, biodesign, materials knowledge, etc.).

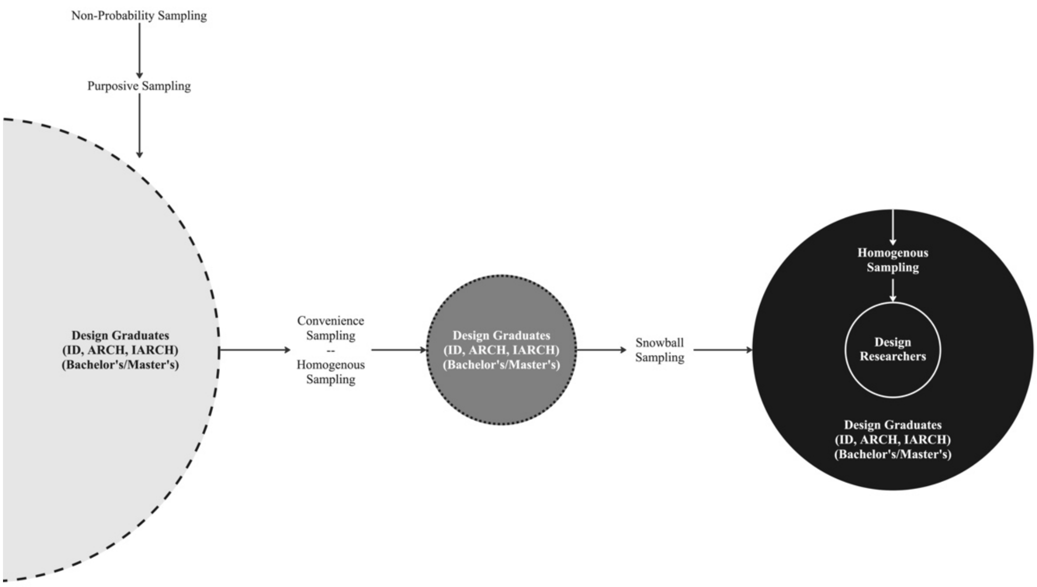


Figure 3.2 Sampling Process Diagram

The demographics of participants in the workshop are given in Table 3.1.

Table 3.1 Participant Demographics

PN	Bachelor's Degree/ University/ Year	Master's Degree/ University/ Year	Occupation
P1	Industrial Design/ Yeditepe University/ 2009	Industrial Design/ İstanbul Technical University/ 2016	Research Assistant
P2	Metallurgy and Materials Engineering/ Sakarya University/ 2012	Industrial Design/ İzmir Institute of Technology/ 2016	Research Assistant
P3	Industrial Design/ İstanbul Technical University/ 2019	Industrial Design/ Middle East Technical University/ 2022	Research Assistant
P4	Interior Design/ Anadolu University/ 2013	Interior Design/ Anadolu University/ 2019	Research Assistant
P5	Industrial Design/ İstanbul Technical University/ 2020	-	Gamification Designer
P6	Industrial Design/ Bahçeşehir University/ 2022	-	Product Designer
P7	Architecture/ Süleyman Demirel University/ 2017	Architectural Design Computing/ İstanbul Technical University/ 2020	Research Assistant
P8	Architecture/ İzmir University of Economics/ 2020	-	Architect
P9	Architecture/ Bahçeşehir University/ 2019	-	Game Designer

3.5.5 Data Analysis

The data that emerged in the workshop were analysed qualitatively. The analysed datasets include voice recordings, data collection sheets and creative outcomes (visuals and texts) from the workshop. Despite taking video recordings for some parts of the workshop, they are discarded from the analysis since, after an initial investigation, they are found to be irrelevant and do not provide further insights different from voice recordings.

The voice recordings during the day took place in every phase of the workshop. The phases recorded are:

- Initial presentation (briefing) session: An hour recording including nine participants and the researcher.
- Generative phases (world-building phase, material design phase and anticipated UX phase): Three recordings from different groups. Three hours for each group, a total of nine hours.
- End presentation session: An hour recording of the presentations of outcomes.
- Facilitation comments: Half an hour of recording feedback from the participants.

Therefore, a total of approximately 12 hours of voice recordings have been taken, and all of them transcribed. Briefing session, end presentation session and facilitation comments are verbatim transcribed to catch the crucial details in the dialogues. On the other hand, the generative phases of each group are intelligently transcribed (i.e., *naturalised transcription*, Bucholtz, 2000), discarding repeated words, stops, and irrelevant sentences based on the emergence of topics since the content of the discussions were more critical rather than the notions within the dialogues. The workshop is conducted in Turkish, although the workshop materials are in English (since there was always a possibility of non-Turkish participants). A transcription tool for Turkish by Voiser is used (Voiser.net) to ease the transcription process. Since the workshop was conducted in Turkish, I have translated the parts I planned to report by myself, trying to be as loyal as possible to the Turkish originals.

Apart from the voice recordings, which are the primary datasets with creative outcomes of each group, data collection sheets filled by the reporters of each group and me are analysed to complement the video recordings. However, on the reporters' side, the collection of data using data collection sheets did not go as planned, and groups filled it together regardless of one of them in each group being assigned a reporter role. I will address this issue in the analysis chapter, but it is essential to underline that assigning such a task to a participant overwhelmed them and did not provide novel data but instead completed the missing points caused by errors and/or noises in the voice recordings.

3.5.5.1 Thematic Analysis

As the primary analysis method, thematic analysis is used to analyse data. Braun and Clarke (2006) define thematic analysis as "*... a method for identifying, analysing and reporting patterns (themes) within data*" (p.79), underlining the ability to describe and compile chunks of data in themes. Moreover, Robson and McCartan (2016) feature thematic analysis as an approach to analysing data using coding systems to create themes. The authors also mention that the themes could occur after the initial data immersion and/or based on prior research (Robson & McCartan, 2016). Since I designed the workshop after my sensitisation process, the categories to position the major themes emerged with the literature review in mind and were considered during the design phase.

To carry out the analysis process, I have benefited from CAQDAS (computer-assisted qualitative data analysis) by using MAXQDA (see Figure 3.3). Robson and McCartan (2016) explain the benefits of using CAQDAS programs (from which I have benefited): the ability to store all data in a single place (data collection sheets, creative output, voice recordings), the ability to reach coded materials and group them, and ability to show the frequency, similarity, encounter of codes. Apart from MAXQDA, I have used Miro for visualising the coding maps.

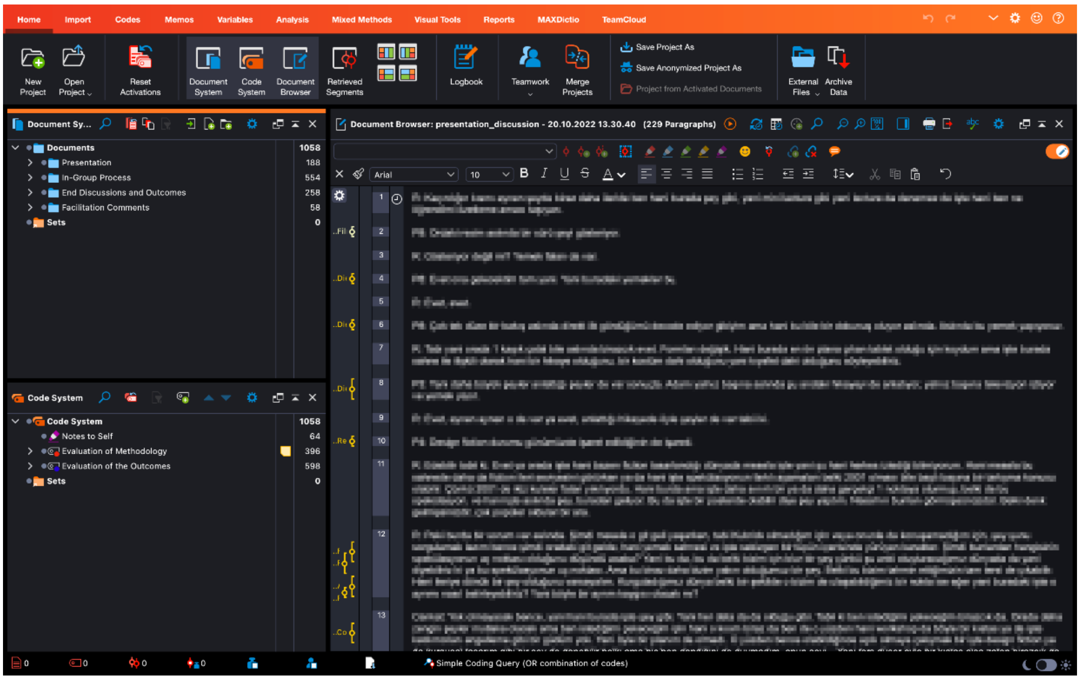


Figure 3.3 An Example Screenshot from MAXQDA Interface

The process is completed in two rounds. Saldaña (2012) describes two coding phases, which are the first round and the second round of coding. Whilst the first round is more generic and less selective, the second round is being initiated to analyse the first ones (Ritchie et al., 2013; Saldaña, 2012). Based on the previous statement, the data coding introduced more specific sub-themes (indexing and sorting), and then I compiled them under major themes (categorising). Lastly, these major themes and sub-themes are compiled under the categories. Hence, the coding process is completed by reviewing emergences in the empirical data and considering what has emerged in the precedent research steps. Whilst that was the case for the most prominent dataset, which was on the future of living materials, another secondary dataset emerged for the evaluation of the workshop. This time, the themes emerged after the initial coding process regardless of prior categorisation. It is also reported in the analysis chapter because designing the workshop, using workshop materials and other aspects were considered capital during the research process.

3.5.5.2 Narrative Writing and AI-Supported Visualisation

Defined by Cambridge Dictionary (n.d.), narrative means "*a story or a description of a series of events*" or "*a particular way of explaining or understanding events.*" A narrative is one of the core features of design fiction and could be positioned as an essential asset for developing novel ideas not just for solving design problems but also for researching the real world (Blythe, 2017). On the other hand, creating narratives from qualitative data is featured by Elliott (2005) and later applied in a study by Pepper and Wildly (2009) from the interview after further processing the field data. Being able to be processed later, the datasets that emerged during the workshop were very suited to creating narratives even without further detailed processing. Hence, approaching these data after completing the thematic analysis, I created narratives by reorganising the shattered definitions of Storyworlds into an order sourced from the flow of the workshop. However, I would like to underline that these narratives are included to complement understanding the analysis process rather than constituting an additional set of analysed data. Despite these facts, I have contacted the group members of each group to obtain their approval and suggestions for adaptation/change as necessary.

While creating the narratives, I benefited from everything produced and recorded after the group work had been initiated, such as each group's in-group discussions, end discussions, creative outcomes, and data collection sheets. Combining and selecting each item participants have not disregarded; I shaped a narrative for each group based on their speculations. However, despite adopting an interpretivist approach, I have not included these narratives in the thematic analysis process as they could blur the reporting of what happened with what I imagined having happened. However, while creating the narratives, I tried to be as noncommittal as possible while interpreting the Storyworlds.

Moreover, to complement and support these narratives, I used Midjourney AI to visualise the Storyworlds. "*Midjourney is an independent research lab that produces a proprietary artificial intelligence program that creates images from textual descriptions"* ("Midjourney," 2022). The reason behind using an AI program is that it offers quality visuals with text descriptions within a limited time. Primarily, while creating images including future concepts, Midjourney is already regularly used by a few designers for various reasons (including fun) and listed in everyday design magazines (such as designboom.com, dezeen.com, Core77.com, yankodesign.com). Also, with design fiction placed as the centre of the methodology, using an AI tool (e.g., Midjourney AI's '*/imagine*' command) would create complementary speculative results, beneficial for imagining the future of living materials. The Midjourney results are provided as figures in Section 6.1, including the keywords to prompt the AI tool. Each group is assigned with a random colour (emerged collectively with the AI tool) to create a theme in the narratives.

3.6 Summary

In this chapter, I presented the methodological grounding for my empirical study to achieve my thesis's aim. This thesis investigates the future of designing with living artefacts using design fiction methods by exploring the possible speculative experiential potentials, cohabitation possibilities, practices, and attitudes when we switch from inert products and infrastructure to biologically alive replacements.

I explained the research approaches I intended to follow. Initially, I positioned my research ontologically and epistemologically within a broader perspective. Then, I explained my primary research approach: participatory action research. Second, I addressed the research ethics in my studies for Phase I: Biodesign Sensitization and Phases II and III: Design Fiction Workshop. Third, I explained the theoretical foundations of my sensitisation process, which was conducted as a personal field trip which I voluntarily carried out and not included as an empirical study but instead considered as hands-on post-secondary research.

Lastly, I described the theories I benefited from for the workshop. For my empirical study, I adopted the *research through design approach,* more specifically, *research through design fiction approach.* To collect data adopting these approaches, I aimed to use design as the collection method, along with field notes and voice recordings. Then I clarified the sampling process and concluded the chapter with my data analysis method, thematic analysis. The primary analysis method is accompanied by using narratives as a research strategy and visualisation of such narratives to complement the thematic analysis and create an image in the reader's mind. In the following chapter, I will present my post-secondary research (sensitisation process through a field trip), including the details.

CHAPTER 4

PHASE I: BIODESIGN SENSITISATION

Considering biodesign as a sensitising concept, I visited the Netherlands to improve my knowledge regarding working with living materials. As explained in the methodology chapter, this was a personal effort to enhance my knowledge and acquaintance. The primary reason for me placing emphasis on personal development as a part of my thesis studies is that the immaturity of the field, especially in Turkey, directed me to obtain first-hand knowledge that could complement literature findings. As an industrial design graduate and an MSc student in the same area, I had a chance to work with living materials for a brief period while studying for my bachelor's degree. However, it was personally not enough and some time ago. The data presented in this chapter comprises anecdotes and personal discoveries rather than a dataset to be scientifically analysed. The findings are reported and explained in chronological order of the visit, from a personal perspective, including thoughts and reflections.

4.1 Visiting the Netherlands

Since the beginning of Spring Semester 2020/2021, there had been an idea of organizing a field trip to be more sensitised to the biodesign concept based on the direction of the study. Then, with this in mind, my thesis supervisor and I contacted Prof.Dr. Elvin Karana from TU Delft to arrange a field trip to the Netherlands. The field trip was initially planned for the beginning of May 2021, but because of COVID-19 travel restrictions and ongoing lab constructions, the visit was postponed to mid-July 2022. Then, for the arrangements, I initially issued a passport, bought plane tickets, and obtained permission from my workplace. However, due to the ongoing crisis in passport issuing in Turkey, my passport did not arrive within an acceptable period. I therefore had to visit Ankara to be issued my passport in-person two days away from the departure date. I flew to the Netherlands from Izmir on July 9^{th} and returned on July 17^{th}. I stayed in a pre-arranged accommodation during my visit and covered all expenses myself. In the following sections, I will present what I have done to sensitise myself to biodesign and how my sensitisation activities and anecdotes affected my thinking around the research topic and questions. I separated my visit into two main parts that were profound for building my knowledge: Visiting a biodesign lab and conversations with researchers.

4.1.1 Visiting a Biodesign Lab

Before my conversations with the experts, I was allowed to observe a biodesign researcher while working in a lab. The biodesign lab (namely Material Incubator Lab, at Avans University of Applied Sciences) was a Level 1 Lab (BSL-1). A lab level indicates biocontainment precautions taken while constructing the lab and the interior organizations to do so (Chosewood & Wilson, 2009). BSL-1 is the lowest biosafety level for the labs suitable to work with organisms that do not cause any diseases in case of contamination (Chosewood & Wilson, 2009). However, despite being BSL-1, I was not permitted to work in the lab because I had no lab training, and it was inconvenient to be trained given the time constraints. The lab I intended to visit was still in construction at the time; therefore, instead of that lab, I was able to visit an alternative. The initial purpose of my visit was to become knowledgeable about a specific organism, namely bioluminescent algae (pyrocystis fusiformis), on which I initially planned to design my workshop and main research focus. However, bioluminescent algae were not present at the alternative lab I visited (see Figure 4.1), and none of the current biodesign researchers were working on the algae. This situation led me to adapt my research focus and questions slightly, as well as change the direction of my research design; nevertheless, having implemented a flexible research approach, I could adjust my research despite surprises.

Figure 4.1 Biodesign Lab Environment

The most important inferences from the lab were primarily on working with living materials in terms of a MDD (material driven design) perspective. As was presented in the respective article, the first stage of the MDD method starts with a material tinkering process (Karana et al., 2015). In *Scenario 3* ("*designing with a material proposal or a semi-developed material or exploratory samples"*, as listed by Karana et al., 2015, p.39), material tinkering is characterized mainly by understanding the material's experiential and technical qualities. Based on that, when the material is living, the first stage of the MDD process takes place in the lab by understanding the *living qualities* of the material, as well as understanding the needs and requirements of its livingness apart from technical and experiential qualities. Therefore, I think the material tinkering process for living materials takes longer than when the same method is applied to non-living materials. Moreover, working with living materials requires a multidisciplinary approach to the materials, where a designer and biologist work together because the working tools are primarily within the scope of the latter, but the aim is within the former.

4.1.2 Working with Living Materials

As seen from Figure 4.1, working with living materials requires, if not completely, a very different understanding of a 'workspace' compared to a design studio. The safety regulations within the lab mostly correlate to safety measures in a biochemistry lab rather than a design studio. I was able to observe one researcher working on one specific living artefact, but most of the stages in preparing a healthy environment for a living material follow a similar procedure (Arora, 2013). The procedure is named *cell culture media creation*. It is the process of growing cells in a controlled environment, primarily outside their natural ones. Each step of the procedure is demonstrated in Table 4.1, constructed from the visuals and field notes I took.

Table 4.1 Steps in Cell Culture Preparation

	The process starts with the decontamination of the tools used in the process. For decontamination, chemicals such as bleach or isopropanol can be used (Chosewood & Wilson, 2009). It is essential to decontaminate the tools since the growth of the organism could be affected by the presence of any other organisms that might be present in the lab environment during the following steps of the culture creation.

Table 4.1 (continued)

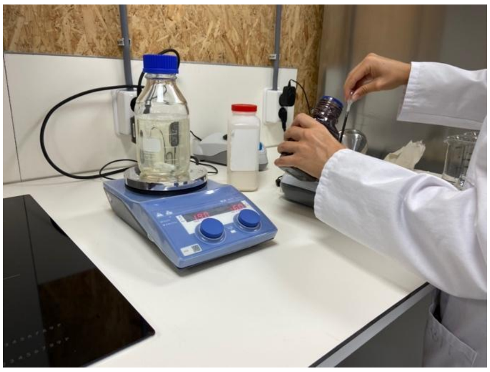
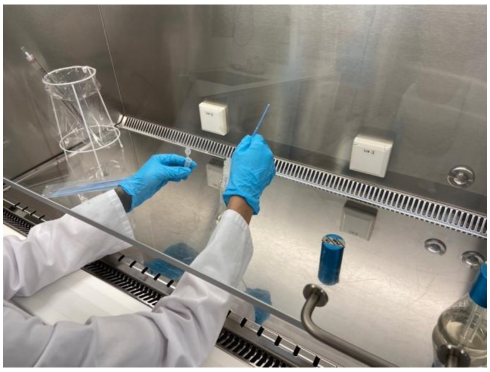
	After the decontamination process is complete, the growth media (i.e., *"a solid, liquid, or semi-solid designed to support the growth of a population of microorganisms or cells…",* "Growth Medium", 2022) is created for the organism based on the intensity level of the desired composition. The media can be in various intensities, such as pure liquid, semi-liquid (gel), or solid in some cases, and the intensity of the media can be varied with different materials based on the type of organism ("Cell Culture," 2022).
	At the same time, the nutrients and other necessary minerals are added to the media to provide the optimum conditions for the organism (Arora, 2013). Therefore, the step should be carried out meticulously because these variants also affect other conditions, such as pH and osmolality (Arora, 2013).
	If necessary or required, other ingredients can be added to the media. In the picture left, an additional substance is added to the media to reveal the design potential of the organism. However, this step is not obligatory and does not affect the growth rate or the organism's health within the culture.

Table 4.1 (continued)

	After the media preparation, it is placed in the autoclave machine. An autoclave machine is used for the decontamination of the media by applying heat and pressure (“Autoclave,” 2022). It is used before adding the culture of organisms to the media as it maintains a sterilized environment for the media.
	Lastly, a culture of organisms is added to be grown in the media. After adding the organism, which is in its dormancy, the culture is placed in an incubator which provides optimal environmental conditions for the thriving of the culture. The culture can be grown without an incubator if the organism's tolerance is high.

Elaborating on the stages listed above, it was clear that even solely tinkering with living materials (without any application or design in mind) requires novel skillsets and understandings. This process takes place before the intention of designing biodesign products. However, as a crucial step to prolong livingness to the use phase of the artefacts, it becomes more apparent that the importance of the process does illustrate the attention required for the pre-design phase of artefacts. Hence, as also mentioned in the literature in Section 2.4.2, it is clear that attention to the incubation, maintenance, and caring of the culture is fundamental to living materials, and any products in which they are placed, and therefore requires a particular way of approaching it. **Addressing these steps and the literature, the incubation and care processes of living materials and artefacts will be as indispensable in the future as they are in the present.**

Moreover, these steps also underline the importance of a sterile environment for the wellness of the living material and define the requirements for an organism, whether to be encapsulated in a closed environment that allows closed interactions or embedded into the media which allows open interactions. However, for an organism to be embedded into a media and stay alive within an open interaction, the organism's tolerance should be high and not get easily affected by the presence of other microorganisms in the environment and other environmental factors such as light, pH, minerals, etc. However, as these developments go hand in hand with biotechnology research and development (Grushkin, 2021), **it is possible to foresee that an organism, once it is found to be viable in an artefact that resembles a big petri-dish, can at some point in the future be embedded into media that allow open interactions.**

4.1.3 Conversations with Researchers

As in any other usual field trip, I was able to talk with experts with first-hand practical experience in biodesign and living materials. The conversations were carried out informally and the questions asked were based on my biodesign knowledge, which I attempted to extend and become more sensitive towards. Using biodesign as a sensitising concept, I was looking for small notions or insights that would enhance my understanding of the matter. For this purpose, I took brief field notes entangled with my lab-visit inferences. I did not analyse these notes in a systematic way (they were not considered a dataset), but instead I sought to understand the extent to which they matched or differed from the literature. Therefore, I will list the most critical memos in bullet points, by relating them to my secondary data research, especially to Karana et al.'s (2020) article on conceptualizing livingness as a material quality. The article illustrates a broad explanation in terms of designing and living with living materials (microorganisms in this case).

Regarding the organism's needs:

- Each organism needs varying environmental conditions to thrive, such as humidity, heat, nutrients, oxygen, etc.
- It is possible to maintain the livingness by reproducing colonies.
- Based on their sensitivity, the organism might require a sterile environment which makes the interaction possible with only a closed petri-dish system (as stated in Karana et al., 2020, p.48). Otherwise, livingness can be embedded directly into the material and make livingness a material quality.

Regarding the organism's behaviour:

- Organism behaviour is the main inspiration for such mutualist relationships intended to be maintained in the first place.
- Moreover, temporal aspects of living materials, especially responsiveness, adaptiveness, and changing nature (Ertürkan et al., 2022), stand out as prominent behaviours in terms of design potential.
- The unpredictable nature of the organism yields novel possibilities for discoveries; however, it also makes the material / artefact design process harder and time intensive (Camere & Karana, 2018a)

Regarding the human perspective:

- Humans adopt a custodian role within a mutual relationship; it especially becomes vital for maintaining the organism/material/artefact and the reproduction of colonies.

- Complementary to the custodian role, empathy, product attachment, and emotional engagement can be essential drivers for maintaining sustainable relationships between humans and organisms.
- Genetic modification might be a prominent paradigm regarding the future of living materials.

4.2 After the Field Trip

After handling everything I had read and carried out, I simplified my learning outcomes. As explained earlier, the effort of becoming sensitised towards a subject allowed me to elaborate on what had been gained from the literature review. Based on my field notes from the lab visit, my conversations, as well as the literature, it is useful to consider the existence and maintenance of living materials or living artefacts as reliant on a mutual relationship, illustrated in Figure 4.2.

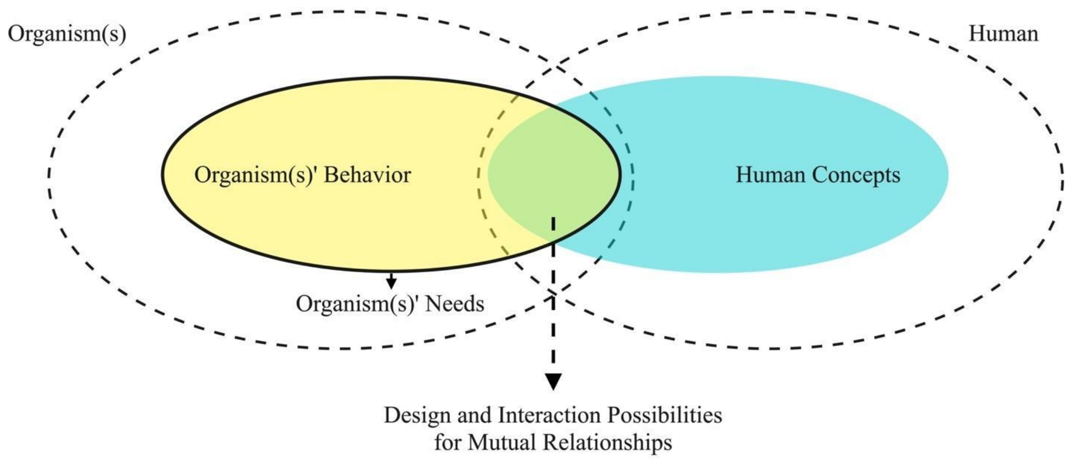


Figure 4.2 The Two Ends of Mutual Relationships

Elaborating on Karana et al.'s conceptualizing livingness (2020), the way I have sensitised and then mapped showing the relationships between organisms and humans for the purpose of prolonging livingness to the use phase has helped me to develop a tool for the empirical study of this research. Therefore, as it helped me to develop a speculative workshop, it could be beneficial in designing further studies for researchers and practitioners in terms of not just designing workshops but also design proposals of any kind.

In Figure 4.2, there are two main clusters: human and organism. Regarding the design of artefacts embedded with livingness, humans stand as a starter for mutual relationships under certain concepts, as explained in the paper before, such as sustainability, MX, empathy, emotional durability, etc. On the other hand, organisms (often microorganisms), which are found in nature, demonstrate particular behaviour which matches the scope of such human concepts; however, for organisms to thrive as if they are in their natural environment and behave as they are observed in nature, the organism's biological needs should be fulfilled.

So, to create mutual relationships embodied in artefacts, the organism demands that certain pre-conditions are met, which often outline the design criteria for an artefact before considering any interaction with humans. Therefore, the intersection of human concepts and an organism's behaviour forms the cluster of 'design and interaction possibilities for mutual relationships', so long as the organism's needs are provided for.

Zooming into the intersection of two major clusters, Figure 4.3 shows the interrelations between the two major stakeholders within the relationship. The discoveries of design and interaction do not necessarily have to follow the same path. An organism's behaviour, after the observation, might be the starting point of a way to discoveries, but a human with the intention of designing can look around the environment to find an organism and create such relationships. What is critical here is that for the human to start the relationship, the organism's 'need barrier' should be considered as one of the essential criteria of design and the core of material tinkering activity.

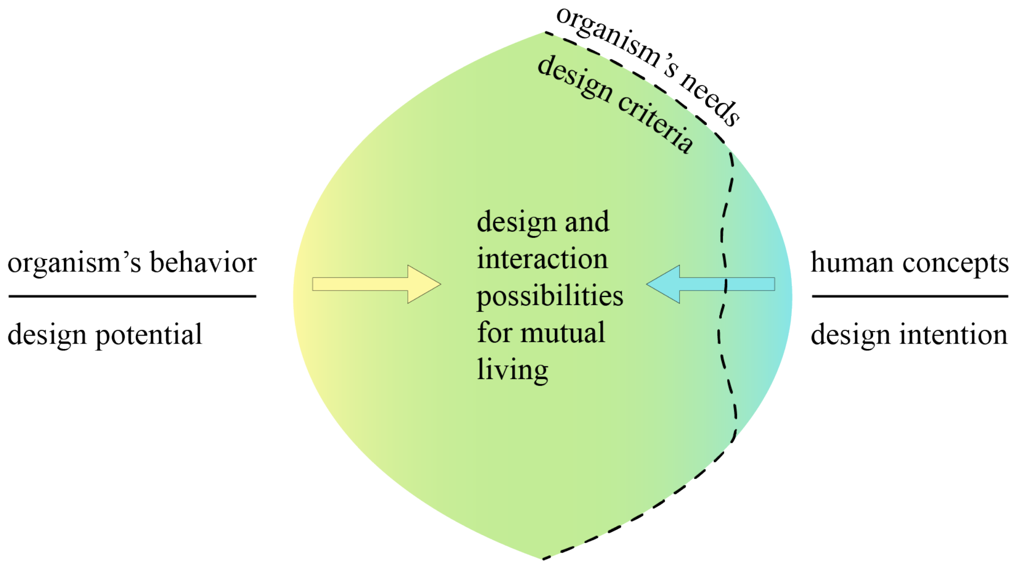


Figure 4.3 The Intersection of Humans and Organisms Within the Frame of Living Materials and Living Artefacts

I would like to correlate the figure by illustrating an example in the literature to make it more straightforward. Elaborating on Aghighi's Biogarmentry, it is possible to see the human concepts, organism's behaviour and needs together. However, I have assessed the example based on my knowledge based on literature and visuals so that this mapping can be elaborated (see Figure 4.4). Yet, I believe that creating such a sensitisation tool allowed me to see the clear connection embodied in artefacts between humans, organisms, and design.

Figure 4.4 The Assessment of 'Biogarmentry' (Aghighi, 2019) Based on the 'The Two Ends of Mutual Relationships'

As I approach the end of this sensitisation chapter, I want to summarize my thoughts. First, designing a map such as Figure 4.3 will be an important asset for the next phase of the research because as I have sensitised to the concept of (living artefact as) biodesign for myself, I am planning to find a way to allow workshop participants to also sensitise to biodesign and living materials. Consequently, the map can be considered a sensitisation tool that is handy for three reasons. First, as it was to me, biodesign carries the potential to be a challenging concept since it is a novel research area that risks alienating the participants of the workshop, which is preferably prevented. Second, I would like to clarify the issue of cohabitation by distancing it from the earlier biodesign approach, in which the primary driver is the notion of utilization (rather than mutualistic care). Third, when design fiction is implemented as a research tool, it often concentrates on human concepts regarding the future (e.g., future themes in design fiction such as cyberpunk, artificial intelligence, decentralization, etc.) (Bleecker, 2009). These are useful when used for story world creation (Coulton et al., 2017) but might be harder to relate to fictional futures for very focused concepts such as biodesign, living artefacts, MX, etc. which are obligatory to include for this research.

4.3 Summary

In this chapter, I presented my sensitisation activities in the Netherlands. Instead of carrying it out as an empirical study, I position my effort as a private activity, yet it profoundly affected my knowledge. Therefore, I prefer to name it a practice-oriented post-secondary research or a sensitisation process which helped me sensitise on particular concepts such as biodesign and living materials. With this goal in mind, I visited a biodesign lab to increase my knowledge of working with living materials and had conversations with researchers to explore the practical details I could not reach through only reading.

After the field trip, I compiled what I learned during this sensitisation process and presented them in the chapter. That process was helpful in terms of gaining more-than-published knowledge and being able to design a further refined workshop in my journey to answer my research question. In the following chapter, I will present my design process, how I carried the knowledge I gained from the literature review and the inferences I made from the sensitisation process to the design process.

CHAPTER 5

PHASE II: DESIGN OF THE GENERATIVE SESSION

Adopting *research through design*, and more specifically, *research through biodesign fiction* approach, I designed a workshop as my empirical data collection method within the scope of my research aims and to be able to answer my research questions. In this chapter, I will explain the workshop's design process, including the initial design decisions that drove me, the final design, the workshop materials, the recruitment process, arranging the workshop setting, and conducting the workshop. The 'design' here stands mainly for the creative graphic and workshop mechanics creation process, but as featured by (Stappers & Giaccardi, 2017), there is a notion of *"doing design is doing research"* (p.7), which defines the effort I intend to present in this chapter. By carrying out the visual design for the workshop, I shaped the research design; by carrying out research, I shaped my visual design. Because of that, despite mentioning design as the graphic and workshop mechanics design process, it is also related to the *design of the research.*

5.1 Design Process Overview

Before starting the workshop design, based on my literature review and prior personal experience, I already had theoretical and practical knowledge regarding carrying out a design fiction workshop. My practical knowledge was based on applying a design fiction workshop to 3rd year undergraduate Industrial Design students. Therefore, my supervisor and I were able to collectively develop a draft plan for the workshop, which was quite helpful for the following process, given the time constraints and often intense, time-consuming design process. With the draft plan, I applied to the ethics committee to obtain ethical clearance to carry out the workshop.

Then, I started the design evaluation process by carrying out further complementary research focused on the *application of design fiction* in both grey and academic literature, example applications, and prior designs -a common practice at the beginning of any design process- and compiled these files in a separate folder. Such a research process can be linked to the market research that designers often carry out before starting any creative design activities. In line with that, my prior knowledge emerged from the initial literature review and my earlier personal experience, which I have gained by being an *industrial designer* (of which I have a bachelor's degree), and my current role as a *researcher* has helped me to shape the design of the workshop.

5.2 The Draft Plan

The draft plan for the workshop, which my supervisor and I collectively shaped, is presented below. With the draft plan, I applied for ethical clearance to complete my empirical studies on August 18, 2022, and received approval on September 12, 2022, from Applied Ethics Research Center, METU (see Appendix B). The draft plan defined the outline of the eventual workshop, which involved some upgraded content and minor changes to the flow of activities. The draft plan was as follows:

Pre-Session Preparation

I. Briefing documents, presentations, and audio-visual stimuli will be distributed to raise participants' general awareness and knowledge on the subject of 'living materials and biologically alive products/infrastructure' before arriving for the session. Participants are expected to view and read the provided information.

Generative Step I – Living Materials Design

I. Each participant (individually or as a pair) will be tasked with designing a fictional living material. It might be based on a plant, algae, fungus, bacterium, etc., that has been raised or engineered to exhibit a specific functional characteristic (i.e., useful in products/infrastructure) alongside its inherent livingness characteristics. Livingness characteristics define the conditions needed to thrive/grow (e.g., the material requires specific nutrition, water, light, humidity, space, care rituals, etc.).

II. A specific functional characteristic will be randomly assigned from a provided shortlist. That will define the unique function-oriented property of the material (e.g., luminescence, stickiness, strength, elasticity, water repellence, etc.) Participants will be assigned just ONE functional characteristic for their fictional living material, acting as the 'headline' or 'main reason' for using it.

III. The material may be conceived as a mass/bulk and/or a coating/surface finish. Participants will be asked to visualise the material, name it, and create a biography/personality. Such material characterisation is familiar to designers – hence, the session will harness participants' existing creativity, ideation, and communication skills at this step.

IV. In the end, participants will present their materials, with the researcher acting as facilitator and moderator of discussions.

Generative Step II – Usage/Application Scenarios

I. Participants will explore and propose usage scenarios and products/infrastructures that utilise the functional characteristic of their fictional material. Scenario building and proposing solutions for new products/infrastructure are core skills of the designer participants.

II. In the end, participants will present their usage scenarios, products, and infrastructure ideas, with the researcher acting as facilitator and moderator of discussions.

Generative Step III – Anticipated UX

I. Participants will empathise as owners, users, or custodians of the living products/infrastructure proposed in Generative Step II. Participants will work in groups.

II. The objective will be to define (speculate) the anticipated user experience (UX) of interacting with and CARING FOR [e.g., having an analogy to caring for a baby/pet] the living material. Possible dimensions to be used as cues for UX anticipation may include: time spent caring, replacing, feeding, cleaning, tidying up, disposal of waste, watering, re-energising, etc. The designer participants will re-cast their existing competence in UX towards the anticipated UX of fictional living material. Participants will choose the medium and techniques for conveying the anticipated UX.

III. In the end, participants will present their UX speculations, with the researcher acting as facilitator and moderator of discussions.

Final Debriefing

I. The researcher will provide a general review of the conduct and outcomes of the session, indicate how the results will be used, and ask for feedback based on participants' experiences.

5.3 Workshop Mechanics and Content Design

Elaborating on the draft flow, I decided to upgrade the draft plan based on three primary drivers. First, literature and market research regarding the application of design fiction, 1) as an idea generation method, 2) as an empirical data collection method, and 3) as a method applied for creating speculations regarding the future of living materials. Second, during the sensitisation phase I completed; I devised a categorisation method to help me design the workshop materials. Third, the idea of including card decks as a motivational and fun tool to enhance participants' creativity during the generative session makes it comparatively less of a task and more of an interactive game-like gathering. With that in mind, I designed the workshop to be completed in groups.

5.3.1 Market Research

Apart from the literature that explains the theoretical foundations of design fiction as a speculative design method, I have researched different embodiments of design fiction as *design artefacts* and *research artefacts,* with the workshop in mind. The reason behind this diversification was to separate -as I have addressed before- the research design and the workshop's creative design from each other. Therefore, I will present my findings based on that categorisation and mostly exclude *the design of the research* as I have completed its theoretical grounding in the methodology chapter. On the other hand, since such research and assessment of tools is not within the scope of this thesis, I will present my findings briefly, considering them as assets that shaped my design decisions and market research on what could be found in the market rather than a literature review per se.

Initially, based on my prior research and the research I carried out during the market research, the idea of applying the workshop in a card deck format was not new. Despite exceptions, the visual designs regarding design fiction are often carried out directly with cards, or cards are being situated to be used as a supplemental tool with other materials. However, some of the applications were in line with the design of the workshop I intended to design compared to other ones.

Regarding the aim of empirical data collection and creating speculations in bio futures -if not directly but relevantly- I have reviewed the workshops applied by Çağlar (2021), focusing primarily on the last stage where participants could speculate regarding the creation of their diegesis. Another source, The Lean Futures Creation Handbook (Futurice, 2021), led me to include *world-building* as an initial stage where participants could shape their diegesis before creating their living materials, products, and experiences. Regarding world-building, Coulton et al. (2017) state: "*Applying world building to Design Fiction moves the focus away from storytelling (e.g., narrative, characters and/or plot) and instead places importance on the cohesion of the world and how things and people within that world interact* (pp.14-15)." Hence, redesign of the flow took place by including the *world-building* phase in the workshop to create diegesis for the easier creation of entry points (interactions, products, experiences, materials etc.) that could be situated within.

The content aimed explicitly at guiding participants towards speculation of living materials. With this aim, Ertürkan et al.'s (2022) article regarding the creation of novel vocabulary for living materials was beneficial apart from the entire literature review and my personal experience. The emerged keywords in the article (Ertürkan et al., 2022) have also been used for the creation of a speculative storytelling card deck (Affect Lab, 2021); however, the categorisation of the refined keywords did not entirely match with my keywords, so I have benefited from the initial categorisation given in the paper which is more diverse. I also tried to find an article regarding the workshop application or the actual card decks, but I could not. Nevertheless, combined with my categorisation mainly emerging from the sensitisation process, the vocabulary was inspirational while creating the content of the card decks of 1) *behaviour of the living*, 2) *caring for the living*, and 3) *design and interaction possibilities*. Apart from the living materials vocabulary, some of the keywords used for speculations for *world-building,* such as the keywords in the 4) *global challenges* deck and 5) *global opportunities* decks, were also included in The Lean Futures Creation Handbook (Futurice, 2021). 6) *provocative deck,* which is used as a supplementary deck to create speculations, is created without further research. 7) *living needs* deck emerged from the needs that are common to all living beings (Arora, 2013; Jones & Jones, 2014), diversifying some major needs into more specific categories (e.g., environmental needs into dryness, moisture, humidity, etc.) and the sensitisation activity. 8) *material trends* deck emerged from the literature review and my knowledge of materials and design. Lastly, 9) *material affordances* deck is shaped by being influenced by the everyday affordances that conventional materials have.

Regarding the graphic design of the workshop, simple icons and/or illustrations are positioned on cards to complement keywords in the market (Affect Lab, n.d.; Near Future Laboratory, 2022; NTU IoX Center, 2021, etc.). Evaluating card decks as boundary objects; *"...objects which are both plastic enough to adapt to local needs and constraints of the several parties employing them, yet robust enough to maintain a common identity across sites* (Leigh Star & Griesemer, p.393)," I decided to limit the use of visual influences. Hence, I created card decks including only keywords without any type of representative or associative image.

5.3.2 The Effect of Sensitisation Activity

Preliminary to the workshop's design, the main reason behind the sensitisation activity was to gain insights regarding the making processes of living materials by adopting the combination of roles of a designer and researcher. Following such a road, the visit enriched my personal experience regarding biodesign, which was limited to theory. Since research through design by definition requires 'design action' to carry out the research, sensitisation was crucially important to inform the workshop design. Therefore, I positioned the outcomes of my sensitisation process (see Section 4.2) from the visit at the core of my workshop, which was especially important for Step II: Material Creation (see Section 5.5) as much as Step III: Diegetic Prototyping (see Section 5.5). As stated in the respective chapters, the two ends of mutual relationships (organism and human) become apparent when this relationship is formed by 1) discovering the novel behaviour of organisms by humans with a concept in mind and 2) if the human utilises the behaviour of the living material through providing a cohabitation environment and necessary care actions for the living material. Taking the categorisation from the sensitisation activity (see Section 4.2) as a basis for categorising the card decks of the workshop, I created card decks as prompts to assist participants in their generation and conceptualisation of livingness and materials at the relevant phases in the generative workshop. These decks are combined with more general categories purposed for the creation of the diegesis specifically (see following sections).

5.4 Transferring Written Data to Visual Outcomes

Overall, combining my market research and inferences from the sensitisation process, I have compiled written data I produced in various digital platforms such as Microsoft Office and Miro. After, I concluded the process by embodying and converging the written data into a combination of visual and written data. Consequently, for the workshop: 1) A poster (see Appendix D); 2) nine card decks (total of 254 different cards) (see Figure 5.1 and Appendix E); 3) a working sheet for participants (see Figure 5.2); 4) a set of semi-structured data collection (for groups and me, Appendix C); 5) a tips brochure for participants (see Appendix F); 6) a presentation (see Appendix G) have been designed. The design of the poster is entirely carried out using Adobe Illustrator. On the other hand, for the card decks, working sheets, data collection sheets, presentation, and tips brochure a combination of Microsoft Office (e.g., PowerPoint, Word, Excel) and Adobe Illustrator have been used.

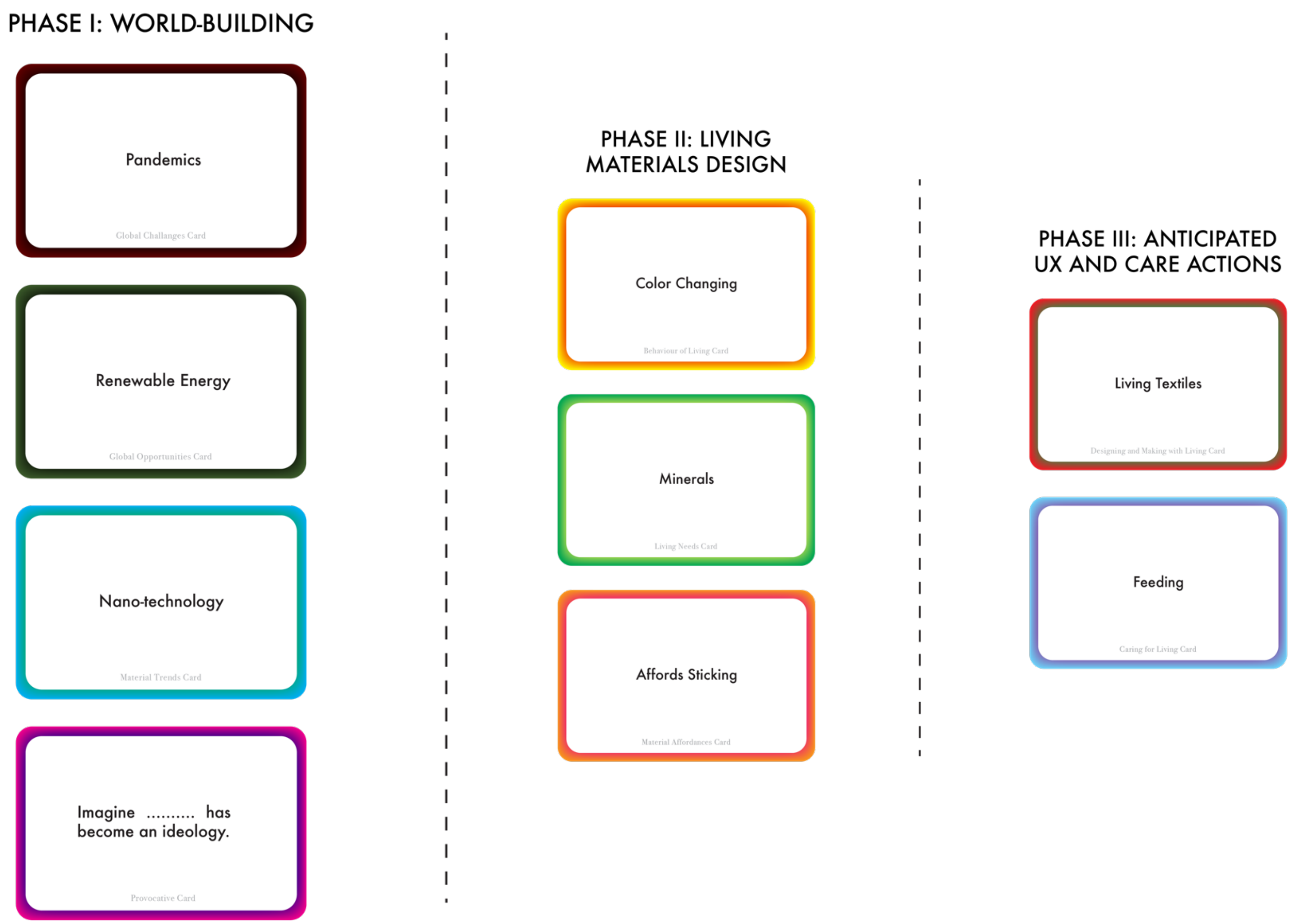


Figure 5.1 Example Front Pages from Each Deck

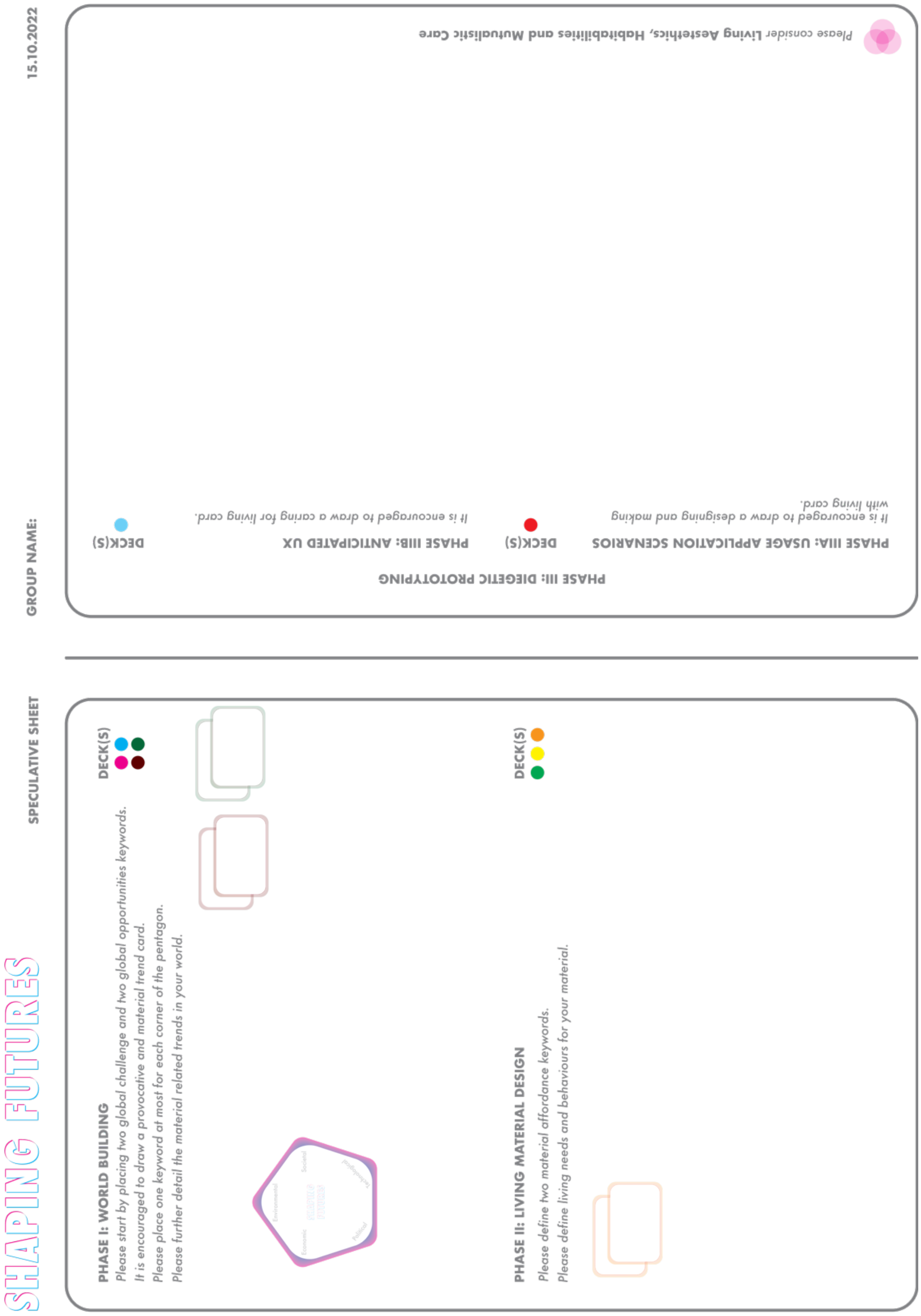


Figure 5.2 Working Sheet

5.5 The Final Content and Flow

After assessing the influences mentioned in the earlier sections, the workshop's final content and flow are presented below. Complementary to understanding the flow, the examples from each deck are shown in Figure 5.1, and the working sheet is illustrated in Figure 5.2.

Presentation and Discussions

Materials: 1) Presentation; 2) Tips and Flow Sheet; 3) Working Sheet

Step 'zero' of the workshop is an informative session in which the researcher presents the subject. However, the presentation will not be in a conventional format; rather, it will be in a discussion format where the researcher chats during the production and asks questions as they proceed instead of taking questions at the end of the presentation.

Generative Step I: World Building

Materials: The following card decks were designed and produced: 1) global challenges deck: the emerging and present challenges which are foreseen to be prominent in the future; 2) global opportunities deck: the emerging and present opportunities which are foreseen to be prominent in the future; 3) material trends deck: the materials and design related trends to ease the bridging the world-building phase to living materials phase; and 4) provocative deck: cards that are aimed to create a debate between participants.

Participants are expected to design a world in which they further speculate, starting by taking two cards each from the 'global challenges deck' and 'global opportunities deck' and placing them.

I. Express the world as descriptively as possible by filling in the pentagon and defining other details. (For this, participants should take cards from the ‘provocative deck’ to help them to think the different aspects of their diegesis.)

II. Imagine the future of materials and production practices in the world that is created. (For this participants should also take cards from the ‘material trends deck.’

Generative Step II – Living Materials Design

Materials: The following card decks were designed and produced: 1) behaviour of living deck: possible behaviours of the living emerged from the literature; 2) living needs deck: a set of general keywords that define possible needs of the living; 3) material affordances deck: a deck which participants use to help limit their usage of their materials for the following stages.

Participants are expected to design living material(s) considering their needs and behaviours and must start by defining two affordances described by taking two cards from the ‘material affordances deck.’

I. Imagine the future of living materials and define the behaviours and needs for the living materials (For this, participants could take cards from the ‘living needs deck’ and the ‘behaviour of living deck.’)

Generative Step III – Diegetic Prototyping and Anticipated UX

Materials: The following card decks were designed and produced: 1) designing and making with living deck: cards to aid participants in creating product concepts with their material; 2) caring for the living deck: a set of general keywords to lead participants precisely to shape their care actions.

Participants are expected to embody the created material on a product in a context that emerges from the world-building activity by considering the topics related to conceptualising living artefacts.

I. Explore and propose usage scenarios and products/infrastructures that utilise the affordances of their material. (For this, participants should take cards from the 'designing and making with living deck.')

II. Empathise as owners, users, or custodians of the living products/infrastructure proposed in the previous activity. (For this, participants should take cards from the 'caring for the living deck.')

Final Debriefing

Participants will explain their Storyworlds, living materials, products, and experiences around those products. Then they will provide feedback on the methodology.

5.6 Recruitment and Conducting the Workshop

After the design process had been completed, the recruitment process was initiated. I prepared an e-mail for possible earlier participants two weeks before the workshop to recruit participants. As explained in the sampling section (see Section 3.5.4), the requirement for participants was to have a bachelor's degree from a design department (namely, ID, ARCH, IAED or IAD) who had previously taken a materials and design course regardless of their current profession. Therefore, I initially sent the e-mail to those I knew who matched the requirements based on convenience within a shortlist I had earlier prepared. In the e-mail, I wrote down a welcoming phrase for the workshop, research question, consent form and the overall flow without giving further details providing a Google Forms link that asks only for the name-surname info and their participation status. Only three people had filled out the form in a week and stated their availability. Because of that, I have updated the e-mail making it shorter, easier to read, and easier to answer and added an endnote asking to forward the e-mail to the ones they know who match the criteria. However, with that effort, only two members were added to the list. Then I decided to change the platform and designed a mobile message, so that prospective participants could become snowballs and help me recruit more participants, which worked better than sending e-mail. Within a day or two, I reached 12 prospective participants who filled out the form but nine attended (see Figure 5.3).

Figure 5.3 The Workshop Environment

While arranging the place for the workshop, I applied to Istanbul Technical University for a location/room reservation since I have been working there, and it would be convenient regarding participants' attendance and my working schedule. Based on the sampling, since I intended to complete the workshop with professionals, I had to carry out the workshop on a weekend to match the participants' schedules. Then, I started buying the necessary equipment and arranging printouts for the workshop. In the e-mail, I asked participants to bring their own digital/physical ideation tools such as computers, tablets, sketching equipment etc., and I have provided the following.

- Video and voice recording equipment.

- A copy of the A2 poster; A copy (60x90mm) from each deck of cards, a total of nine decks, 254 cards; four copies of the A1 working sheet; Twelve copies of A5 rules brochure; three copies of the A4 Workshop data collection sheet; twelve copies of A4 Consent forms.
- Post-it notes; a pile of A3 papers; a pile of A4 papers; additional drawing and sketching tools (markers, liners, pencils, etc.); sticking material (patafix).
- A kettle; filter coffee machine; teabags; coffee; water, and paper cups.
- Lunch

On the workshop day, three of the participants did not attend due to last-minute updates, so I was able to carry out the workshop with nine design professionals/researchers at Istanbul Technical University, Çatı-3 on October 15, at 11 am (see Figure 5.4). The workshop took about seven hours with breaks.

Figure 5.4 Workshop in Progress

5.7 Summary

This chapter presented the design process of the workshop. First, it collectively outlined the design process and research design by correlating *doing research* with *doing design.* Then, the workshop flow and mechanics are explained, along with the creation of visuals. Market research (with literature review) and sensitisation activity influenced the design process. Lastly, recruitment progress and the day when the conduct of the workshop took place are presented. In the following chapter, I will present my analysis outcomes and findings that emerged during the workshop.

CHAPTER 6

PHASE III: ANALYSIS OF THE GENERATIVE SESSION

The analysis of the workshop has been completed under two major themes considering the research questions. It is indented to understand the efficiency of the workshop as a speculative design tool and to understand whether these speculations could provide insights towards the future of materials and design.

In addition to the thematic analysis method, I have used another method to complement the main analysis which was helpful to provide results in a holistic manner. First, after completing the analysis process, I created narratives by selecting and reorganizing the participant's distributed statements, in a process that is complementary to the thematic analysis of the workshop. Then, based on those narratives, I have provided visuals (apart from participants' creative outcomes) using Midjourney AI. The reason behind presenting the narratives and visuals first is to create an idea in the reader's mind of each groups' outcomes prior to becoming more deeply involved in the thematic analysis. Hence, the reporting of the results would be understood clearly.

Second, the thematic analysis of the outcomes from the workshop, which are the emergent points regarding the future of living materials, is presented. Third, thematic analysis of the evaluation of the workshop as a tool for empirical research is presented. In other words, an assessment is made of the effectiveness of the workshop for the purpose of creating speculations. The two thematic analysis processes (future of living materials and workshop effectiveness) proceeded simultaneously. Overall, the workshop consisted of three steps: the presentation, the generative session, and the presentation of the outcomes by participants. All the steps were analysed considering the two major themes and reported in the following sections. To provide consistency in line with the steps, the analysis regarding the future of living materials is presented first, with the analysis regarding the evaluation of the workshop presented later.

6.1 The Future Stories and Scenes with Living Materials

After completing the thematic analysis process, I have created narratives for each of the three participant groups (G1-G3) to create a clearer image in both my and the reader's mind to allow them to clearly follow the analysis process. The main reason behind creating these narratives is because the complex process of the workshop did not provide enough time for participants to create clear narratives and visuals. Consequently, the lack of clarity may obstruct the reader from imagining the actual outcomes of the workshop or the participants' true intentions. Despite the importance attributed to the process rather than outcomes, I believe that carrying out this process offers novel potentials in researching living materials/artefacts through design fiction.

6.1.1 Creating the Narratives and Visuals

While creating the narratives, I used the transcribed data on MAXQDA. After the thematic analysis process (the primary analysis method to draw conclusions) is completed, the concept-related keywords and sentences are selected from transcribed data to create narratives. Whilst most narratives are created based on the direct usage of sentences, only adapting them to provide grammar coherency, I have added my creativity to 'embellish' the narratives to make them coherent for some parts. An example from the beginning of the narrative of G1's diegesis can help illustrate the process (see Appendix H). In the end discussions, they stated:

> At the beginning of this study, the two cards we drew actually triggered the formation of the whole. One is soil degradation, and the other is goods

> consumption and production. There is a state of absence. The second card we chose was the opposite of that. So, on the one hand, we are told that there is nothing and no problem is presented. On the other hand, the scenario of what could happen if you do not have such a human need comes to life in our minds. This contrast was two statically different elements from the beginning.

Then, if the sentences include conceptual keywords/sentences regarding their diegesis, they are marked:

> At the beginning of this study, the two cards we drew actually triggered the formation of the whole. One is soil degradation, and the other is goods consumption and production. There is a state of absence. The second card we chose was the opposite of that. So, on the one hand, we are told that there is nothing and no problem is presented. On the other hand, the scenario of what could happen if you do not have such a human need comes to life in our minds. This contrast was two statically different elements from the beginning.

Also, during in-group discussions of the session, they discuss the reason why the soil is degraded; hence they are marked as well:

> [There is] soilless farming, unplanned farming. Human mistakes killed the land. We had to give up the land to produce food.

Therefore, the sentence is finalised as follows:

> **After years of neglect and irresponsible usage of soil for producing goods to match consumption habits, the soil on earth has degraded so much that humans cannot cultivate and produce anymore.**

After the narratives were completed, I shared narratives with the participants of each group to inform them regarding the creation. The narratives I created received positive feedback, but the participants have not made further criticism.

Initially aimed at the end of the workshop (participants were informed at the beginning of the workshop) but not conducted because of time limitations, I created the AI-generated images using Midjourney AI at the end of the analysis process based on the keywords that emerged from the collected data. The narratives have helped me prompt the AI tool to generate images, providing me with detailed phrases and imaginative pictures in my mind to visualise the outcomes. To conduct the process, I received a briefing session regarding the working principle of the Midjourney AI and help from a friend who had a subscription. The tool can be reached on a chatting software, Discord, and the images are created using the “/imagine” command. Based on my prior research on Midjourney AI and my briefing from my friend, I typed to the command bar 1) a sentence to describe the overall scene, e.g., *a scene of a big tsunami swallowing a piece of land*, then 2) specific adjectives, further descriptions in phrases and nouns, e.g., *people, surface, futuristic* etc. and lastly 3) common adjectives (which are used often in the community of Midjourney AI), nouns, phrases to shape the style of the images, e.g., *hyper-realistic, cinematic lighting, intricate details,* etc. While generating the images, I assigned random colours to each group to create consistency within the narrative and differ from other groups. The tool has been queried multiple times to create the images that best suit the narratives, and multiple sets of images have been produced (more than 200). The decision regarding the selection of the images was based on: 1) coherency with the narratives, 2) coherency in terms of representing the physicality of the diegeses (some images fail to result in ‘meaningful images’ and resulted in abstract representations), and 3) representation of the sensorial aspects (e.g., soft, vibrating, orbicular, etc.). As in the narrative creation process, I only shared the images with participants for informational purposes.

6.1.2 The Stories and Scenes from G1’s Diegesis

The stories and scenes from G1’s diegesis are as follows:

> After years of neglect and irresponsible usage of soil for producing goods to match consumption habits, the soil on earth has degraded so much that humans cannot cultivate and produce anymore. During those years, people were trying to create novel habitats underground, mimicking underground creatures, but more catastrophes were awaiting in the years to come. Years later, without any soil and plants on it, chain reactions caused an increment in climate change. It caused the melting of arctic ice and increased water levels more than had been officially estimated, flooding everywhere on the planet where living is possible (see Figure 6.1). In a world where the soil is no more, people must change their main habitats and adapt their living style

to the only possible one, the water. People tried to live in the ships with saved plant and animal species from the land and practiced soilless agriculture. Still, the increasing numbers in population and shortage of food supplies forced them to think of the possibility of creating a habitat for the recreation of the world. Moreover, being a terrestrial species, living on a bulk of cold iron in a vast volume of water made some humans mentally unstable because of the lack of emotional support and sense of trust that used to be provided by the soil since they broke away from the mainland, from the ground. After years of research for a safe space, it became apparent that humans had to create their own space on the water, and they discovered that the secretion of a novel marine microorganism species seemed promising (see Figure 6.2).

Figure 6.1 (/imagine) a scene of a big tsunami swallowing a piece of land, hyper-realistic, cinematic atmosphere, green cinematic lighting

Research showed that the secretion of the microorganism has instinctive properties that can replace the soil, which makes it possible to combine with water without losing its quality and affords insulation and wrapping. Offering humans an idea of a novel habitat which was viable to be formed on and under water with its gravitational weight and pressure, the initial discoveries show that the secretion is processable by hand, allowing humans to shape it after passing through some stages such as disinfection and drying as an intermediate material and transformed into panels. Thus, forming a structure for a semi-finished product that can be knitted, using only the existing material without a second material. After trials on a loom, it turns out to be that turning it into masses and then into sheets, drying it, and passing it through some reinforcing processes without losing too much moisture (as humans don't want it to lose its elasticity) stand out as the optimal steps to process the material. Then humans bring the material into a form they can knit as if weaving a cloth marking a milestone for creating immense reticulated structures (see Figure 6.3).

Figure 6.2 (/imagine) a picture of material such as algae floating on the sea surface, hyper-realistic, intricate details

The idea emerged of a new city structure: a new city system made possible with the material by using the panels as a building material for habitable hubs (see Figure 6.4). Humans started creating panels to develop novel spaces for themselves where they planned to live, and they initially used the material to form simple modules. In a post-apocalyptic society in which members are united around a basic need, humans shaped colonies in which they can be together and centre the material as a unifying element. Afterward, while forming the additional hubs, they considered modularity with the intersection of public spaces and creating particular areas during the latter formation processes. The general area was much broader and more flexible, which carries the notion of being together. When knitted less frequently, there are more open spaces and more porous structures, which correspond to sociality.

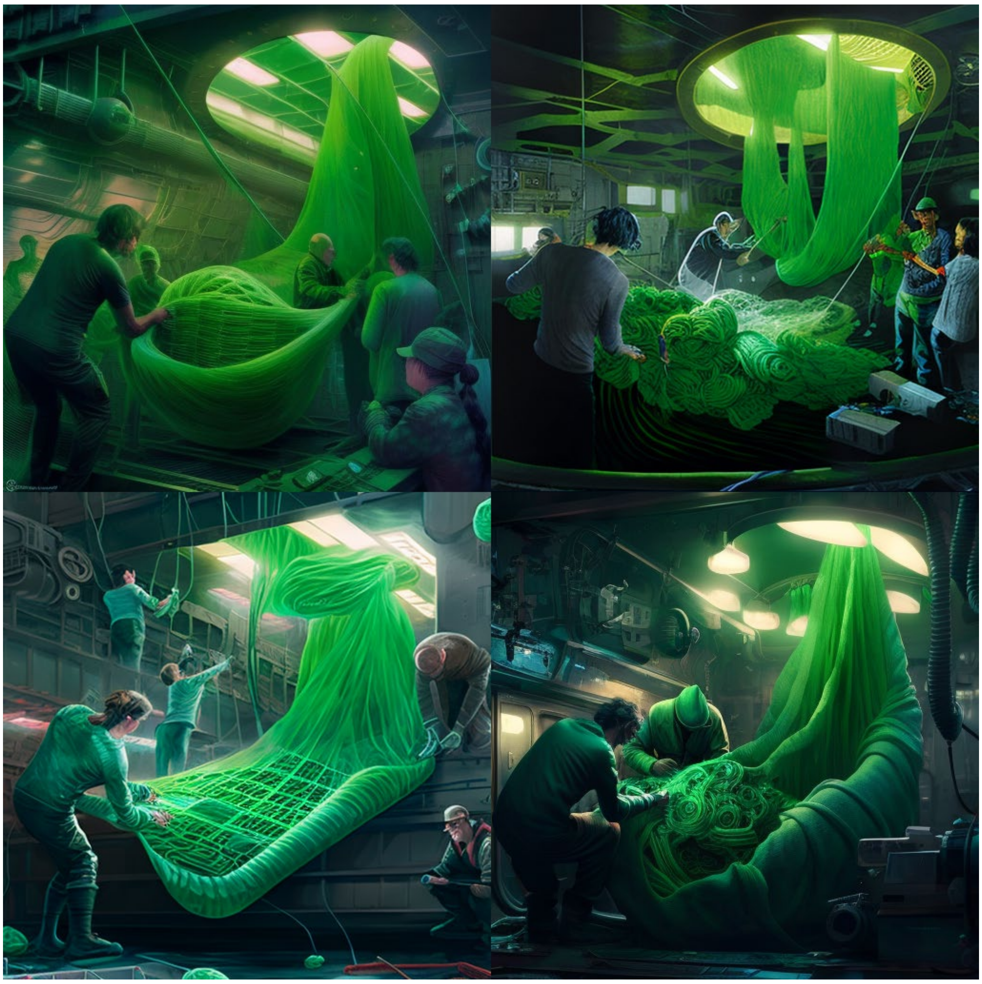


Figure 6.3 (/imagine) a scene of people weaving a futuristic green sticky soft unrealistic material on a ship.

On the other hand, when the knits are made more tightly, the material becomes more rigid, which carries the notion of being hidden somewhere, staying in a secluded place. After all, it was a chance to use the material to correspond to these social characteristics in the world. Hence, they used the affordances of the material to construct their society and communication among themselves socially.

Figure 6.4 (/imagine) a scene of reticulated hubs made of futuristic sticky knitted material on the sea, people, hyper-realistic, futuristic, green cinematic lighting

After habiting in these newly created modular hubs, it is discovered that the secretion is a living entity that renews itself and grows, just like in nature. This organism grows continuously under suitable conditions. While investigating this, it turns out that the material grows with the presence of humans, the investigations estimate maybe with their breath, but it remains still unknown. Therefore, it is agreed that the growth of humans is affecting the growth of living material and secretion. As the number of humans increases, so does the material they feed, care for, and harvest. Since people started living in it, the secretion became alive, creating novel areas on its own which remains in its nature, unprocessed and amorphous in virgin areas like in nature where intervention was as little and as untouched as possible on and underwater (see Figure 6.5). It expands in suitable environments, meaning that it can be increased and controlled. Since it can heal itself, it is found that the knitted parts become varied in qualities over time. They can be separated, torn apart, knitted again, or released as if they always had such an open attitude to processing.

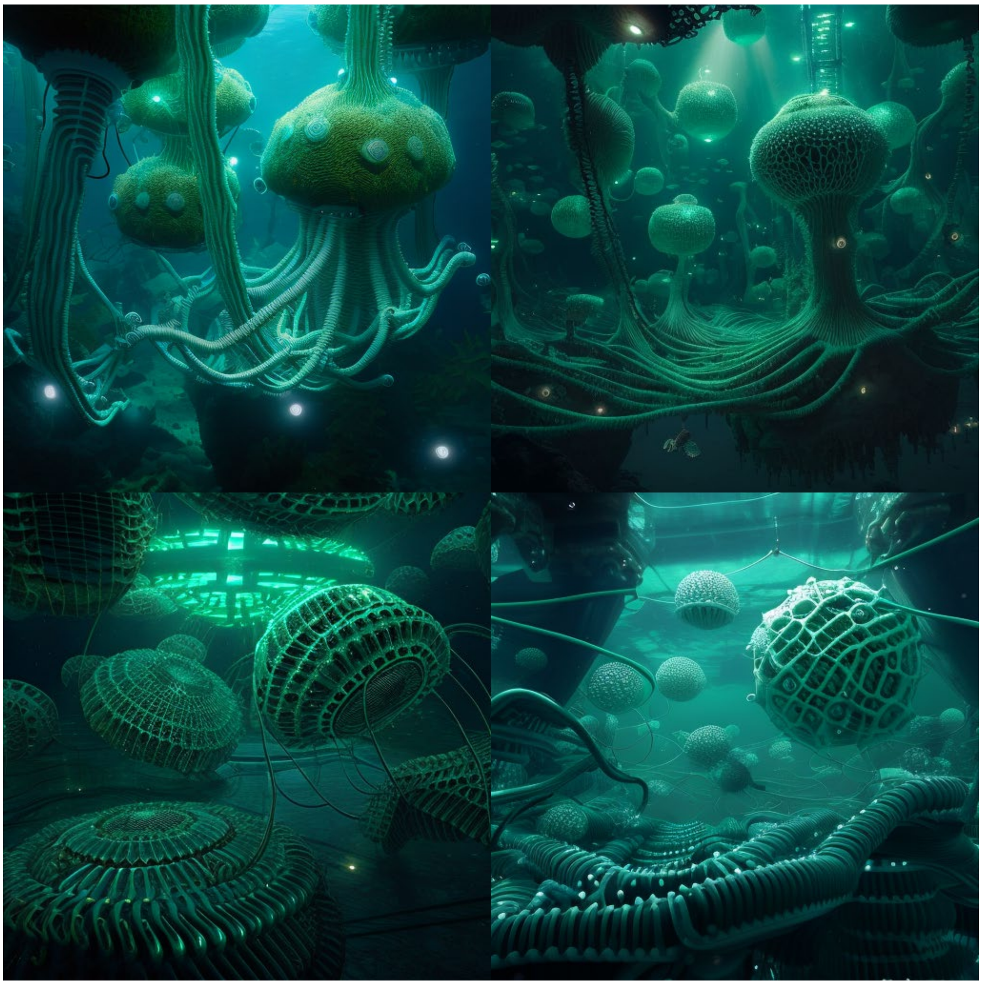


Figure 6.5 (/imagine) a scene of reticulated hubs made of futuristic sticky knitted material underwater, hyper realistic, futuristic, green cinematic lighting

Afterward, it was found that the living material could feed people, creating a fully mutualist relationship in terms of nurturing. For people dependent solely on soilless agriculture, this last development makes the secretion, which was already precious in terms of structural abilities, extraordinary, making it the particular species that constitutes our life not just in terms of creating a place to live but also creating food sources. In time, this artificial yet natural material decreases physical and mental problems caused by the humans' separation from the mainland. Making up for the deficiency and meeting physical and mental needs, the material becomes a second nature, a new source of life (see Figure 6.6).

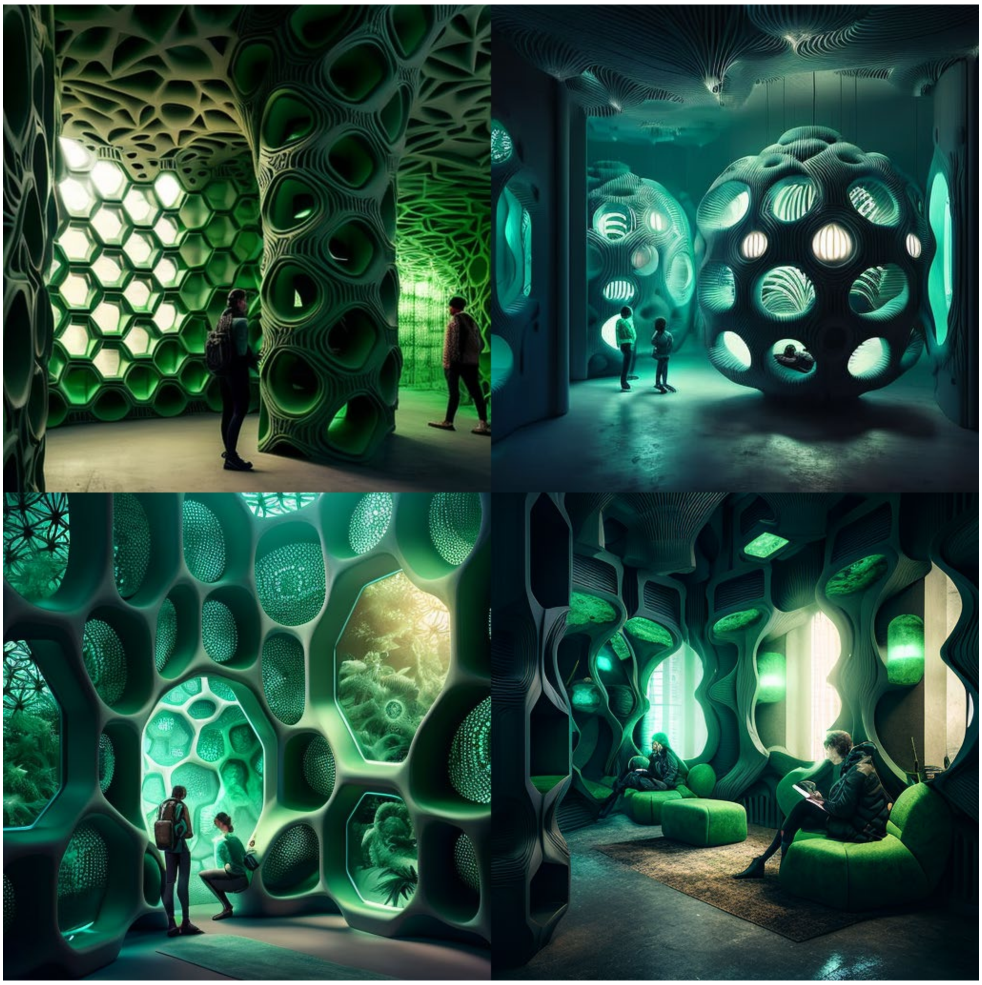


Figure 6.6 (/imagine) interior of a hub, reticulated walls are knitted with futuristic sticky soft organic living material, people, hyper realistic, futuristic, green cinematic lighting

6.1.3 The Stories and Scenes from G2's Diegesis

The stories and scenes from G2's diegesis are as follows:

> The concept of self-expression… That is what brought us here. The emergence of social media was marking a turning point in our society. Throughout the years, we became so addicted to it that we carried it to the most extreme levels. Now, we are living in a world of intrusions. People are trying to expose themselves so severely that they live in transparent structures (see Figure 6.7). Their lives are shaped based on what others will see and think of them. We know we used to do it, but it was mostly in digital environments. Since digital expression became too common, we faced the physical version of it. Welcome to the future of self-exposure.

Figure 6.7 (/imagine) a zoom-in picture of an apartment made of transparent glass bricks making the interior visible, hyper-realistic, futuristic, cyberpunk, cinematic lighting

There have always been privacy violations in the context of the Internet, such as mobile commercials, which would show us what we've been talking about, or webcam speculations that could be controlled by someone else. For other people, there was always a desire to expose what they were up to. The two existed dialectically, but the situation now is much more exaggerated. Everything began with a misconception of what is digital and physical. Some genius people came up with the idea of living fully transparently by posing a simple question: “The digital world is where we share our lives, so as a physical reflection of this,” he asked, “Is it possible to have a life with completely transparent structures in cities?” Starting that day, it became such a common trend that people changed entire structures with transparency, making interiors visible, a structure that would allow invasion of privacy (see Figure 6.8).

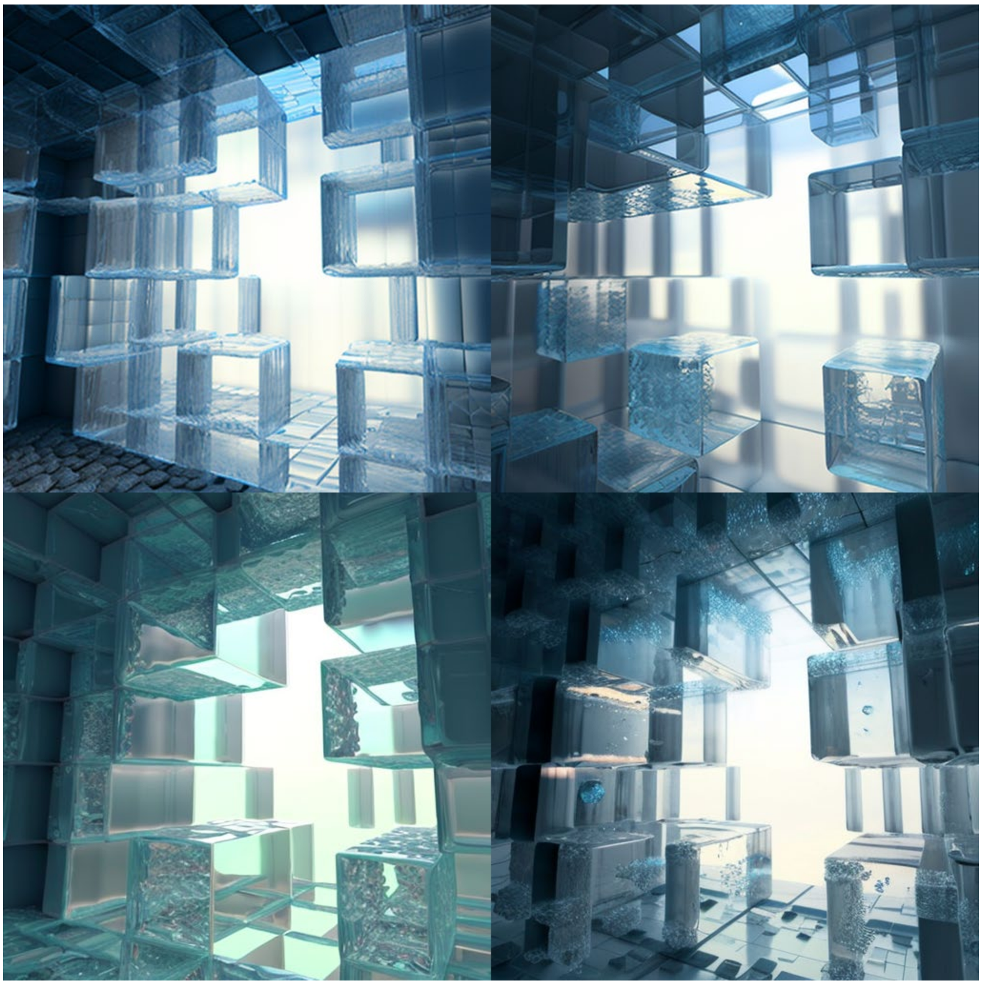


Figure 6.8 (/imagine) interior made of transparent glass bricks, hyper-realistic, futuristic

The transparency created a flat hierarchy where heterogeneous communities are shaped, minority groups are accepted, and different lifestyles and tendencies are accepted as a preference. There are non-binary genders, and since the more-than-human-turn became an ideology, the relationships are lived not only amongst people but also with non-human creatures and objects. Morality and shame disappeared years ago. Since there are such open houses without windows and doors, the concept of family has been set aside. Even motherhood disappeared in this transparent, high-tech world. Transparency also created immense misinformation, since there is always a sense of competition in the instinctive nature of human beings and the urge to display themselves. So, the world has become a place where people can speculate about each other and derive misinformation from a tiny bit of visual data on what is already open and on display. Everyone is visible, but on the other hand, misinformation is produced about the same people, so there is no judgment of any sort. People are not exactly the person they want to be anymore, but they expose themselves as the person they want to be. They may start acting like the person they want to be in their private life, and then expose themselves like that.

With the developing technologies along with transparency, body-hacking became mainstream. People obsessed with self-expression made body-hacking a tool to express themselves, creating expressive cyborgs out of themselves. Due to cyborgization, the digital environment in which people display their lives has extended so much that even transparency of the structures in immediate areas does not affect them. Hence people's interaction with each other is reduced, especially regarding dialogues, language use, etc., and talking has become so blasé that no one seems to be practicing it.

Years ago, scientists developed a plant-like material that requires usual plant care, but which deteriorates when exposed to artificial light (see Figure 6.9). When this plant receives artificial light, some of its leaves decay, and after decaying, it remains as a sticky feature similar to geckos. They designed it to be harvested and used with its sticky and decayed parts. The stickiness does not mean a type of adhesion; instead, its surface and texture qualities change like a hand of a gecko so that people could express themselves with the material, which could be conventionally integrated into clothes. Some reinterpreted the material and used it to maintain their privacy, by closing certain parts of the transparent walls after harvesting its decayed parts. But afterward, it became an indispensable tool for anarchic groups that could use it for protests. Then it was withdrawn from the market.

Figure 6.9 (/imagine) a futuristic plant in which one of its leaves is decaying and changing texture becoming sticky, changing texture, reptile skin texture, gecko hand texture, textural, hyper-realistic, futuristic, organic, orange cinematic lighting

After the first product was used by unwanted groups in society, a new living creature was created in the labs using biotechnology. A living material that can give sound which is fed on the extremity of actions carried out by people. While designing the creature, the scientist tried to define its primary source of life; since humans are obsessed with experiences, the idea of the extremity of human behaviours emerged. Initially, they tested the material with extreme events, such as bungee jumping while carrying it. The idea was to feed the material only with the adrenaline secreted by humans but nothing else. Later, they integrated this into daily life—a little slimy, soft, poor creature. When something extreme happens, it scares and needs a hiding place. They designed it to penetrate small spaces such as breaks and joints in a living area.

For example, if a fight in the house or something extreme happens, it looks for a hiding space and instantly hardens and forms crusts on it (see Figure 6.10). Those crusts vibrate based on the extremity level of that extreme situation, increasing a rattlesnake-like sound based on the events' extremity.

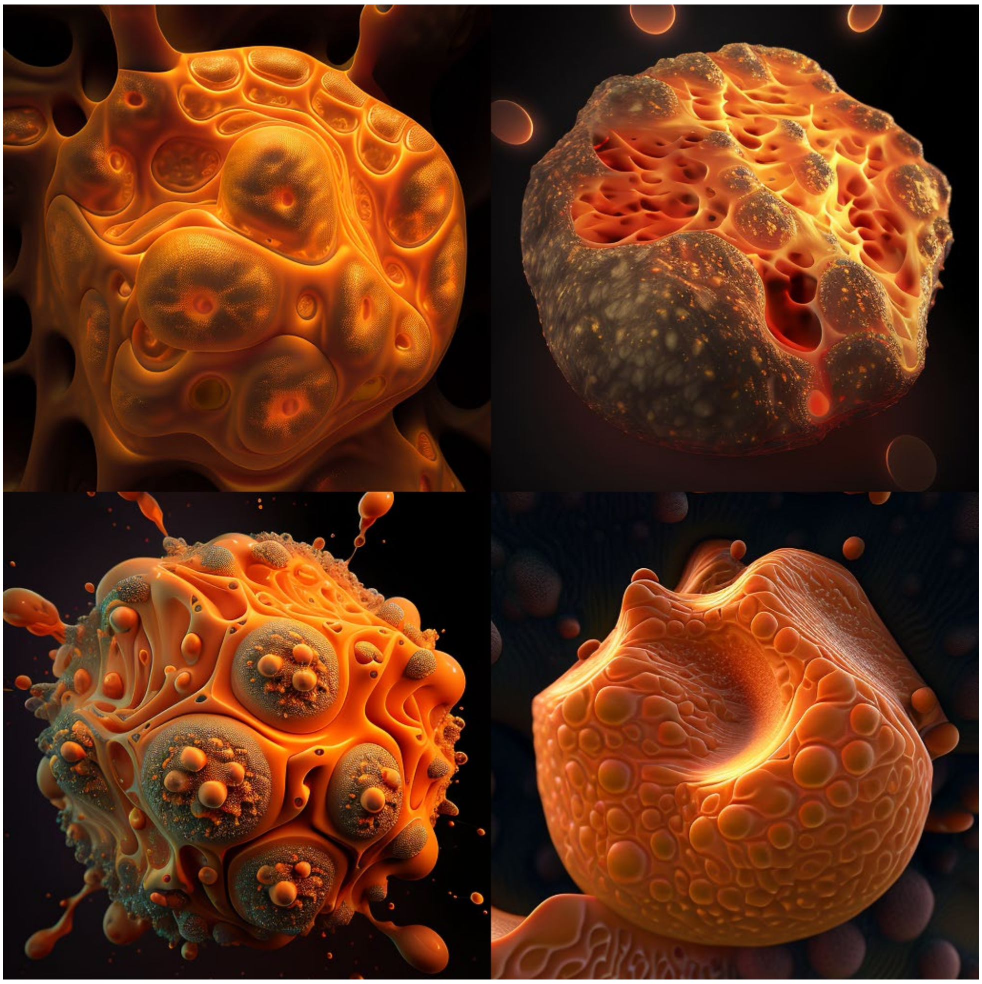


Figure 6.10 (/imagine) a picture of a partly crusted softly seamless orbicular organic slime vibrating its crusts, futuristic, hyper-realistic image, orange cinematic lighting

After scientists completed designing the creature, the designers found a way to integrate these creatures into transparent walls by using it as a living interface to allow people to expose themselves even more by providing feedback. They used the sound-giving feature as a means of communication and self-expression, and they came up with transparent brick structures with walls and corridors within them. Since this creature likes to hide anyway, it is thought that it would happily live there when placed inside the transparent walls (see Figure 6.11). So, people live in the house, and when they are having a party, fighting each other, or having sex, within the framework of these extreme events, the living material also hardens and starts to sound. Thus, that house starts to differ from other houses and attracts the attention of people walking on the street. Then the people would say, “Oh, there is something inside,” which gives a message of self-expression by implying, ‘look at me’, leading people to try more extreme things at home to draw more attention to themselves and contribute to the spread of misinformation. Whether the people inside are having a party, having fun, or maybe having a fight, outsiders would never know since the sound effect is the same. People give information and express something, but the interpretation of that expression is up to the passer-by, which supports the spread of misinformation even further. Exposing has become so normalized that people can go to extremes.

Figure 6.11 (/imagine) a zoom-in picture of a softly orbicular organic slime living in transparent glass brick, hyper-realistic, orange cinematic lighting, futuristic

Nowadays, people are using the initial material combined with the second one. Those who want increased privacy areas are closing the transparent parts and expressing themselves with the second material. In another, self-expression-addicts use the first material to physically climb to the source of the sound and create their judgement so they can feed their curiosity (see Figure 6.12).

Who am I? I am a virus person, a member of a larger group against the invasion of privacy. And I use the misinformation like a virus, spread it around, and use it to hack the order.

Figure 6.12 (/imagine) a person is climbing a transparent monolithic building made of transparent glass bricks in a city, orange parts in some bricks, futuristic, realistic cinematic lighting, hyper-realistic

6.1.4 The Stories and Scenes from G3's Diegesis

The stories and scenes from G3's diegesis are as follows:

> In an over-populated technology-driven world, dictatorship has arisen to control mass human populations in centralized areas. The economy is a mess, and the living conditions are harsh. Since the cruel dictators forced people to work in inhumane conditions to produce energy for the technologies to control more people, some objected to the conditions of their lives and started forming colonies, adopting an ideology against the totalitarian regime. Because of the presence of the government and dictators ruling it, people have decided to create their settlements decentralized and in small populations in remote areas of the world (see Figure 6.13).

Figure 6.13 (/imagine) a scene of steel geodesic cyberpunk tents in desert with a cyberpunk city on the horizon, night, blue cinematic lighting, intricate details, hyper realistic, 32k

The people who ran from the government lived in peace in the colonies; however, the pressure and constant conspiracies harmed the colonies resulting in mass deaths. In one such dogfight between colonies and government, some colony members who will be named legends in the future end up in a bay because of the destruction of aircraft, unaware of their current location. Three people in the sea noticed an indistinct glimpse in the water, but the glimpse was so slight that they would not understand what that was. One of them decides to dive in and investigate the glimpse. After diving, he found out that it was a coral that kept appearing and disappearing in a moment (see Figure 6.14). When he reaches out for the coral, his hands touch the void leaving him shocked and confused at the time. He dismounts it from the ground with his hands to take it out of the water.

Figure 6.14 (/imagine) coral looks like diamond on sea ground, invisible, glitters, underwater, ethereal blue light, hyper realistic, 32k

When taken out of the water, it looked like a petrified diamond. Amazed by what he has found, the colony member decides to take it back to his colonies with other members at the bay with him after a long journey. Researchers in the colonies try to understand the material and ask the discoverer questions regarding the discovery moment and where it has been found. The member explains that his hands touched the void while in the water. Struck on the information, researchers decide to take a trip to the bay where the material is located, and they discover that it is a type of endemic microorganism that lives only in the bay. They collected a culture of the microorganism and samples from the water it inhabits for further investigation.

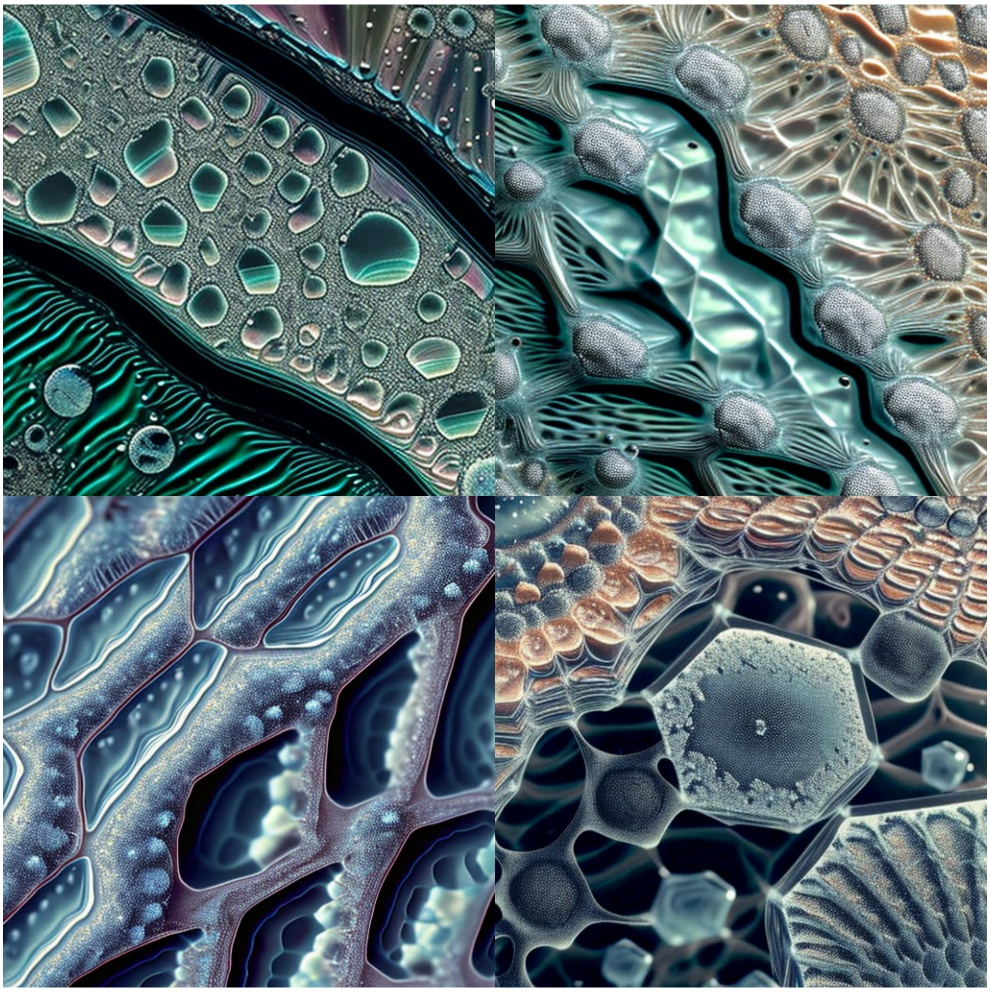


Figure 6.15 (/imagine) a microscopic picture of a microorganism consuming water on human epidermis and producing diamonds, hyper realistic, 32k

While one of the organisms creates a diamond-like material within the same water, the other one makes that diamond reflect the light that can be seen behind the material providing a type of camouflage for the culture. It turns out the bay has the same mineral concentration as human skin, which stunned the researchers. They conclude that, while the initial microorganism creates a diamond-like material, the other behaves like a catalyst on the diamond-like material to reflect the light, providing camouflaging, which is a defence mechanism in nature. Also, both organisms live in the same habitat, which is like human skin (see Figure 6.15). After the discovery, the colony researchers decide to investigate more to benefit from these behaviours as potentials in their daily lives. First, for the first microorganism to behave, they created a capsule where humans and microorganisms could produce diamond-like material together, allowing microorganisms to make a small number of diamonds by using the minerals and water on human skin (see Figure 6.16).

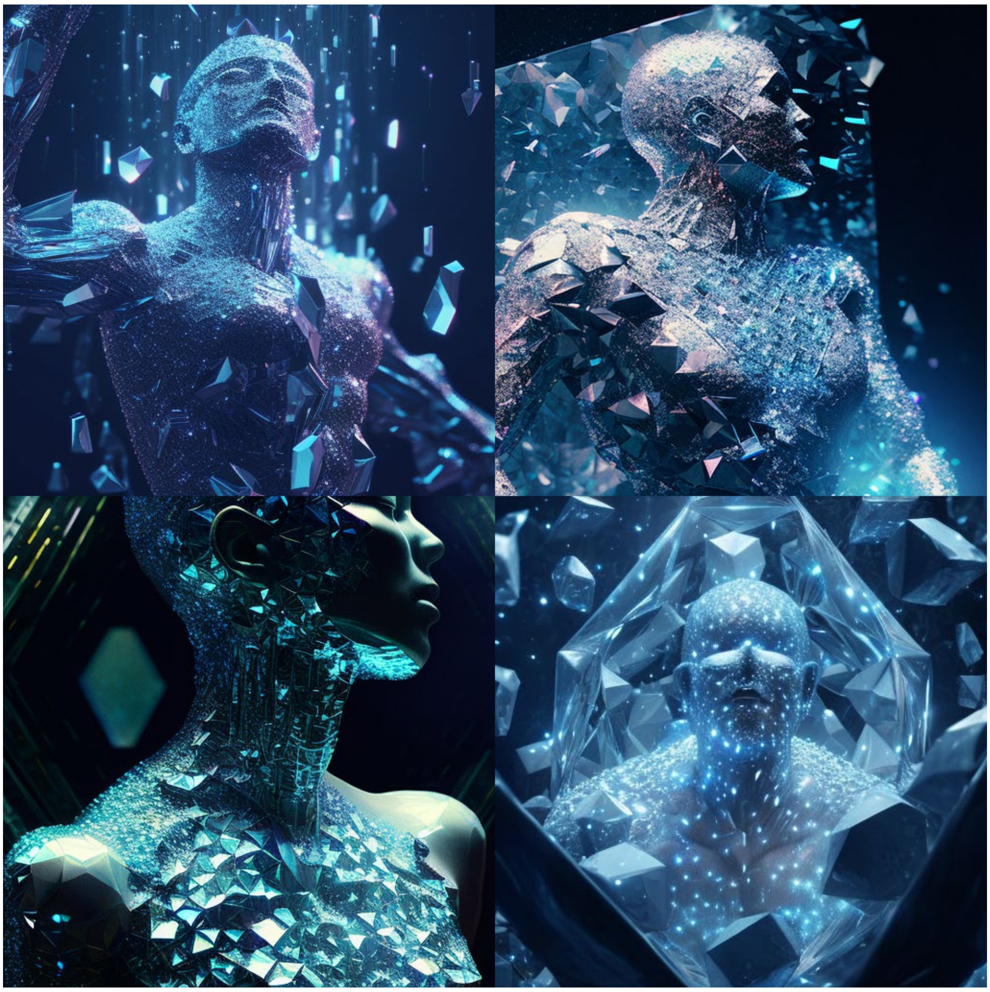


Figure 6.16 (/imagine) human body covered in diamond dusts in a cyberpunk capsule, futuristic, dystopic, blue cinematic light, 32k

Second, combining these two microorganisms in water with the same concentration as the bay and spraying the culture liquid on humans provides the wearer a type of invisibility by reflecting the light for a while until the mineral on human skin is consumed away after an hour to two, using the human body as a catalyst for the initial chemical reaction to trigger the second (see Figure 6.17). Using the human body as a habitat that provides necessary minerals for both microorganisms, they could act against the government but, most notably, live without being detected by the government, hoping their efforts will bring results one day.

Figure 6.17 (/imagine) a picture of a human body sprayed by a blue liquid which makes the human body invisible, cyberpunk, blue cinematic lighting, hyper realistic, 32k

Years later, the energy crisis among the colonies seemed to be solved as the diamond batteries became more widespread. On the other hand, the government, which is still primarily relying on nuclear and fossil fuel energy, is weakened over the years. The concept of diamond batteries evolved and yielded novel innovations. Apart from that, the diamond garment allows the colony members to transport in peace among separate colonies (see Figure 6.18). Still, since it only works on human bodies, the colonies try to develop a method that can initiate the first reaction regardless of human skin to provide camouflage for the equipment they have, but it is yet to be found.

Figure 6.18 (/imagine) a scene of a dark cyberpunk desert with shiny blue foot prints on sand, cinematic lighting, hyper realistic, 32k

6.2 Discovering the Future of Living Materials: Thematic Analysis

A total of four datasets have been analysed to create the most prominent outcome of the workshop: 1) fieldnotes taken by me during the application of the workshop; 2) fieldnotes taken by the group reporters (later filled by all group members); 3) audio files, some of which are verbatim transcribed (i.e., end discussions, presentation session and feedbacks) and coded (i.e., group discussions); and 4) creative outcomes generated by the participants. In total there were 12 hours of voice recordings, data sheets including the notes from the workshop, and visual outcomes produced by the participants.

The analysis process took about a month to complete. It was constructed based on the categories from the sensitisation process regarding working with living organisms. Taking that categorisation as a starting point, I compiled the results under four main categories, which are 1) human concepts, 2) the behaviour of the living, 3) living needs and 4) design and interaction possibilities (with living materials). Figure 6.19 shows the analysis structure, containing main categories, major themes, and sub-themes. As explained in the previous chapter, the workshop design was completed with these categories in mind. Since the sensitisation process formed a logic for assessing biodesign applications, it was also influential for the workshop analysis. Therefore, the research analysis process has been developed upon the idea of analysis of the speculative design process with living materials.

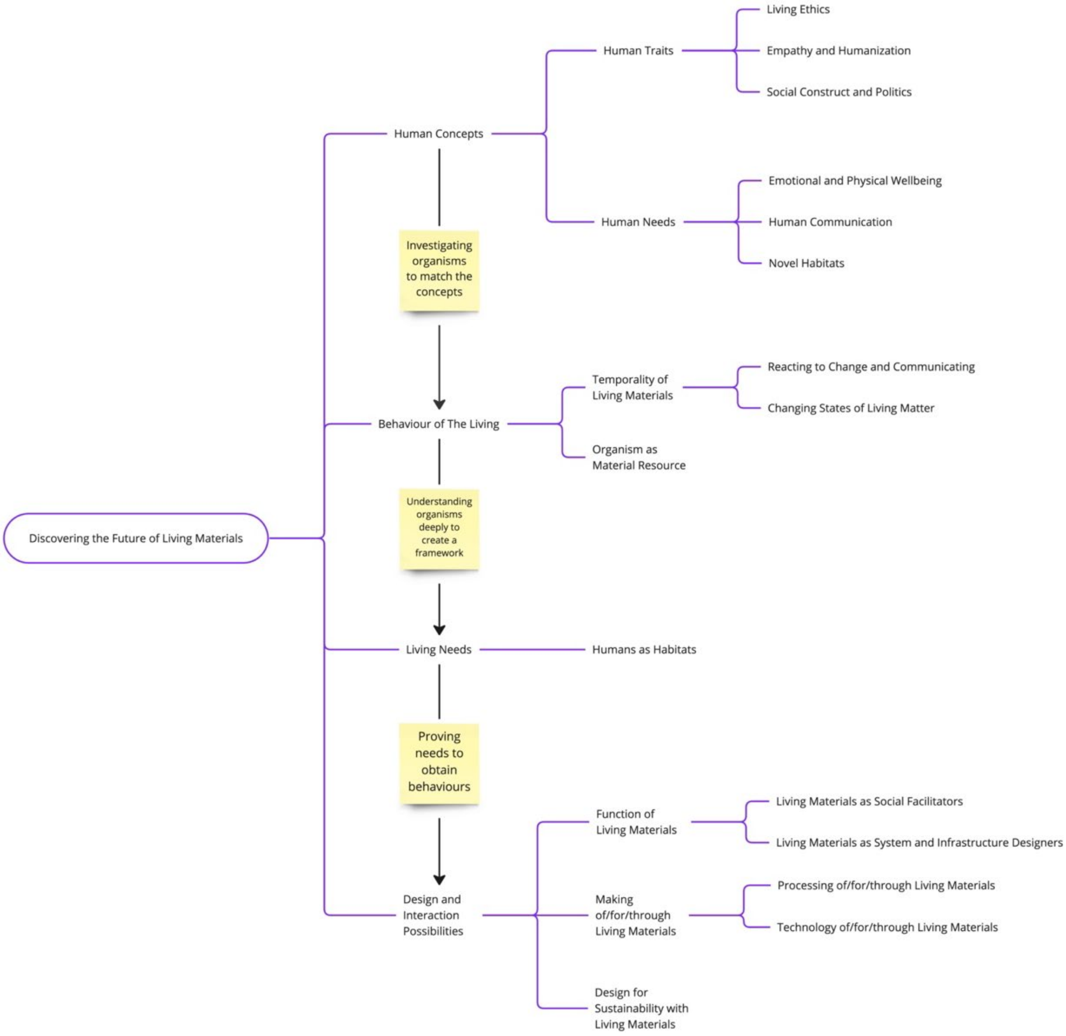


Figure 6.19 Analysis Structure including Main Categories (first column), Major Themes (second column) and Sub-Themes (third column) of Discovering the Future of Living Materials

As Figure 6.19 illustrates, the most forthcoming topic of the workshop was human concepts, which I addressed as *design intention* before. Human concepts were influential during the workshop considering the workshop's design and involvement of design fiction. Its sub-branches are divided into two Human traits stand for the humanistic attributes that came forth during the workshop, whilst human needs represent the essential needs of humans in which living materials would play a prominent role. On the other hand, it has been found that sustainability plays and could play a leading role in initiating the design process with living materials.

The second and third rows in the figure were the categories that were comparatively less insightful compared to others. I will address this point in the Discussion and Conclusions chapter; however, it is beneficial to note beforehand that such concrete categories stay within the boundaries of real-world knowledge without tinkering with actual living material. Thus, speculation is made harder in the absence of familiarity with the reality of living materials. However, despite limitations, the temporality of living materials and assessing an organism's by-product as a material resource were popular subjects regarding the behaviour of the living.

In the last category, namely design and interaction possibilities with living materials, the main category has branched into three major categories: the function of the living materials, the making of living materials and design for sustainability with living materials. However, these categories also shared common points with some earlier categories. Inevitably, based on the flow of the workshop, designing and making with living materials emerged during the last phases of the workshop, making the category to be created with influences from the precedent categories. Therefore, in the end, it created a summary of all that had been discussed during the workshop. Also, when combined with human concepts, the novel findings regarding the social influences of living materials were inspiring in this category. Now, I will investigate the categories explained in this section deeper, presenting direct memos/ transcriptions from the workshop.

6.2.1 Human Concepts

The argumentative structure of design fiction and the nature of the arguments designed resulted in the richness of data regarding human concepts. Since speculation and design are human concepts, the data created by the participants were highly influenced by their conceptualising of their diegesis, materials and products.

What I refer to by saying human concepts are broadly the concepts that shaped by human cognition. It almost includes everything, but here it is evaluated in terms of living materials and positioning of the abstract theories around it. So, from that perspective, everything could be assessed under human concepts. However, the main intention for this classification is to decide the criteria that diversify the humanistic values and thoughts from other attributes specific to design and living materials. In short, I will investigate what is particular to humans in their relationships with living materials under two major themes.

6.2.1.1 Human Traits

Specific psychological and biological characteristics of all humans define human traits. Sub-branches such as living ethics, empathy and humanisation, and social construct and politics emerged dominantly in terms of psychological and sociological aspects.

Living Ethics

The issue of living ethics in relation to designing with living materials was a driving subject even in the presentation phase during the workshop. Especially during the presentation session, even the phrase *living materials* raised critical questions regarding assessing livingness and organisms as materials. One of the participants (P5) stated:

> P5: - I guess I need some moral relief. It is a material, you know, and you want us to move further away from mimicking the living. You want us to come together with the living, but when you say material, I think of it as something detached from the livingness; it goes towards something that I can use and manipulate as I want. I do not think of the harm I would do to it.
>
> P1: - Yes, it is interesting. Conceptually, we commodify the living thing.

As the same discussion progressed, the malpractice of ethics regarding livingness was thought to be related to human actions for livingness to occur. Stating an example from daily life P1, elaborated their initial idea and connected it to a daily practice including a living organism:

> For example, we talked about sheep [outside of the workshop]. Maybe the sheep are not harmed [during sheepshearing], but they are produced in an industrial environment…Even at the level of microorganisms, the same ethical rules come to the fore if they are utilised in industrialisation. Then, in the context of sheep, for example, making use of the milk of the sheep people raise in their own homes and establishing a good life for them.

Based on this statement, it is possible to correlate the words of P1 to Ginsberg and Chieza's (2018) article regarding utilising livingness for human purposes. The issue of livingness within the design domain, the anthropocentric perspective, might create an image of using the living being regardless of their scale or level of development. After, P8 gets involved in the discussion, adding another aspect from a methodological standpoint to the discussion underlining the capability of design fiction in ethical considerations by explaining with a fictitious example:

> Let me give an example from the fantasy world: elves. When we think about it, they shape the trees with magic and live very naturally. The tree is happy, and the elves are so glad they live in it. After all, the universe we have built belongs to us, so maybe we can also create a living material to direct our influence in this way. I mean, there is freedom in that regard.

Empathy and Humanisation

Another consideration of living ethics and, more specifically, empathy was raised by participants while participants were designing their fictitious material and shaping their products with such living materials. Especially in G2's in-group discussions, the ethics regarding the living conditions of the living materials they have designed, to which the group members attributed a behaviour feature of *hiding.* Then creating a relationship between hiding and the act of scaring, they raised small notions considering the ethical part of it.

The attributes common to all living organisms and humans, such as fear, created small moments of notions within the groups. As explained earlier in the paper, empathy makes a vital starting point while designing with living materials. Notions such as ‘what a pity’ or ‘we are morally safe’ show that ethical questioning becomes apparent while designing with living materials. In such situations, participants often came up with the concept of humanisation. In the debates regarding ethics during the presentation session, by providing an example from smart products, P3 said:

> Let me offer a perspective: We have even established a mutualistic relationship with products, especially as products get smarter. A smart vacuum cleaner, for example, a person changes its diaper [dust tank], so it works… There is such a point in the discussions. Those products are that we provide them with something, especially as they start to get more intelligent, and then they provide something so that we can get something back. So, for example, let us say that we are raising awareness. We have created something consciously this time, and its moral mechanism is different.

Also, during the in-group discussions, attributing humanistic aspects, often considered specific to humans, played an active role in shaping the materials. For example, in G1, the material’s *emotional intelligence* was a subject that correlated with the well-being and living conditions of humans. This correlation could also be tied to the concept of biophilia. Whilst emotional intelligence is considered a humanistic attribute, and it could also be interpreted that the well-being of the space in which humans inhabit directly affects human well-being. In that regard, the mutualistic relationship is created by the meanings particular to humans with biophilia and caring for the surrounding environment in mind.

In another, while speculating the relationship between humans and living materials, participants of G2 used human behaviours to create an image within themselves. For example, attributes such as being *asocial* or being able to *watch, observe and listen* are used to detail the living material in the diegesis they have created. Considering these examples, empathy and humanisation would play an essential role in shaping the future of living materials. Especially considering P3’s statement, the intelligent products around have the potential to maintain more robust relationships with users. Living materials might be enhanced regarding relationships between the user and the material when empathy and humanisation are involved.

Social Construct and Politics

The dominancy of social construct and politics emerged even from the beginning of the workshop. Especially some cards in global challenges and opportunities have direct political meanings; however, thinking about the political side of concepts is not unfamiliar to designers while designing. Therefore, both the politics of living materials and the effect of politics on designing with living materials were prominent subjects during the generative session and the beginning of the presentation session. During the feedback session, P4 stated:

> The thing that caught my attention was that such social and political issues were prominent, even while studying the subject of materials. That must probably be related to our department or design, or we are at such a point that social and political parts emerge even on materials. We could not put anything without them, or maybe we did not have such a thought from the start.

So, this being the case, all of the global challenges cards were presented to groups in which they were free to choose, but they had to keep them. G2 and G3 selected challenges cards with direct political meanings (invasion of privacy and dictatorship). On the other hand, despite not selecting a card with clear political implications (soil degradation), G1 interpreted their cards politically and speculated considering politics during the in-group discussion. Based on the talks of all groups, politics emerged while creating the Storyworlds. Politics made a good starting point to create an initial image in the participant's mind to speculate further. Also, by creating a discussion point and problem, the politics often created problems within their Storyworlds that demanded solutions.

G2 dominantly speculated in terms of social construct and politics. While creating their diegesis, they then developed a relationship between their diegesis which was based on speculations regarding social construct, politics, and communication (see also Section 6.2.1.2) based on the card they have chosen and their materials. Speculations (such as the *disappearance of the concept of family*, the *inclusion of flat hierarchy* and *minority groups*, and *change in commodity and moral values)* highly affected their material and product design. In that regard, G2 was the most loyal group in creating speculations in line with their diegesis. Hence, their living material design is situated in what we do not often observe: assessing the material as a social and political influencer. In a sentence, while explaining their diegesis, they stated:

> In our diegesis, we talked about a heterogeneous community with nonbinary genders (something that I would call different minorities) in the LGBTQ+ approach, where minority groups, different lifestyles and tendencies are accepted.

Apart from that, as one of the metaphorical interpretations during the workshop, an affordance card (*blocking*) is combined with materials and speculated with its secondary meaning, 'affords to block so we block the government.' In another, interpreting the term *virus* regarding politics, G2 speculated the usage of a physical *virus* in combination with humans and created a concept of a virus-person to act against the government, protest etc. Regarding G3's material outcome, the material is positioned within the controversy between colonies and the government. So, a debate between the participants occurred about whether the material would fall into the hands of the state. From that regard, the politics of living materials emerged based on the discussion of who would or should have the material, which could also be reinterpreted in terms of living ethics and human rights:

> P6: - I thought of the use of the state, for example, not against the state,
>
> P3: - Of course, it may fall into the hands of the state.
>
> P6: - Falling into the hands of the state, assassination, and stuff like that. You see invisible agents around.

6.2.1.2 Human Needs

Regarding the concepts that affect humans, human needs were a prominent subject in terms of creating diegeses during the first phase of the workshop and embodying materials into products in contact with humans during the last stage. The themes of human communication, physical and emotional well-being and the search for novel habitats have an equivalent regarding human beings' biological and psychological aspects.

Human Communication

Human communication is assessed under two subjects which are social construct and politics, and as a human need. However, it is explained under the human needs section because the starting point of speculation is based on a *need to communicate*. So, inevitably, it could be evaluated under social construct and politics, but the starting point of the discussions created a basis for the categorisation. Especially in G2's diegesis, the different forms of communication emerged while speculating on the urge to self-express oneself within a community. While interrelating the forms of communication in today's world with their diegesis, G2 speculated on how communication would shape a world where self-expression moved the physical world instead of being digital. Also, they connected this issue of *self-expression* to the *spread of misinformation*. While defining their diegesis, they stated:

> We started to see what could happen from our day forward. There is already a privacy violation in the context of the Internet today, but people also want to expose themselves. The two of them exist dialectically, and we thought about what could happen in a situation where this is more extreme in this dialectic. You share a lot in the digital world, and we asked what the physical reflection of this in cities would be. Then we devised a living style with entirely transparent structures so that all our structures are transparent where the interiors are visible. Displaying people's own life has spread so much to the digital environment. Although we have transparent structures, we predicted that people's interaction with each other decreased, primarily verbal dialogue.

As they further described their material and product, social communication remained prominent. They came up with conceptual living material and product which affects the interaction and communication among people, which I will discuss in the following sections. So, this being the case, the living materials in communication between humans emerged as a prominent finding in the workshop, whether it serves positive or negative meanings. In G2, the living material serves the dystopia (referring to their own words) and solves the problem within the dystopia rather than trying to change communication. On the other hand, they did mention it as a problem in their diegesis, but they used their concepts to underline the problem by designing it to serve the dystopia differing from other groups. In their telling, they mentioned it as:

> We have transparent walls, and people also like to expose themselves. People have a vast communication network in the digital environment. Maybe someone in America follows somebody [in Turkey], but they have no communication with their neighbours.

Physical and Emotional Well-being

In line with ethics, empathy and humanisation, the themes such as emotions and sensuality also became apparent in the workshop. Physical and emotional well-being were noted while speculating on the relationship between living materials and humans and in creating the diegeses. While describing their living materials which are speculated to be replacing the soil, G1 stated:

> Then, the soil is central to life, both physically and mentally. Emotional states are included here because what we call soil cannot be considered an object that corresponds only to physical aspects, but a source of life is at least as necessary as water. We tried to produce a material that can replace the soil, artificial but natural as well as soil.

Also, in G1's in-group discussions, debates regarding mental health took place while creating their Storyworlds. Primarily derived from the global challenges cards, while initial discussions were taking place on living underground because of *soil degradation*, the topic of anxiety was discussed in the group. Furthermore, the same group cancels the technology in their world and creates another aspect of their world: sensuality. Disregarding the technology and adding crafting of their living material and sensuality instead, they created a connection between sensuality and crafting, which later evolved to crafting a living material for mental well-being or simply a living material for mental health. Such a meaning is triggered by a material affordance card, namely *wrapping.* In end discussions, they stated:

> We are talking about wrapping, wrapping me up, wrapping us up, wrapping two people, wrapping the whole group. Then it wraps the attendees of this workshop. Then it wraps around Taşkışla, and it wraps Harbiye, it wraps Istanbul. It goes like Turkey and then the world.

P1 contributed to this statement by adding:

> When it comes to crafting like this, we have a relationship with that creature, I would say telepathically. It is like that on its own. For example, as the group here grows, their fields seem to grow on their own.

Also, with the description of their diegesis and material, the other participants commented on G1's outcome stating that using an affordance of a material with the implications created images in their minds. Images such as 'returning to mother's womb', 'it has a side like incubation' and 'because of that separation from the soil, it seemed as if that need for trust could be met with it'. G1 agreed on these comments, and they stated:

> We broke away from the mainland. That is why we chose to move towards such a result by focusing on the search for a safe space. To meet physical and mental needs and to be hidden somewhere. In the process, it was tried to reach things like staying in a secluded place through a single material.

When living materials are associated with material affordances, G1 preferred to recontextualise the affordance of material by interpreting the term with its metaphorical meaning, which I believe to be very interesting. It could be interpreted from the material affordances standpoint, and another aspect of materials could be defined while designing with living materials.

Novel Habitats

The theme of novel habitats has different interpretations regarding the living materials and could be evaluated under design potentials. However, during the workshop, novel habitats often emerged as a human need where participants speculated regarding the needs of humans when humans inhabited new locations. In that sense, it could be tied to space travel trends, mars colonisation, and *climate change*. These keywords (which could define novel habitats without further speculations) were provided to the participants, but none of the groups chose these cards as a starting point during the workshop; instead, they followed their path in creating speculations by choosing different challenge cards. However, all the groups defined vital concepts in providing unique surroundings, strengthening the theory of the presence of living materials in novel habitats.

Based on G1's diegesis, in a world without soil, they were the group in which the novel habitats had the most profound effect on their further speculations. Starting from a prevalent issue, soil degradation, they took one step further in terms of their speculative level and created a novel habitat for their diegesis. Even while designing their living material and interactions around it, solving the adaptation of humans in novel habitats was the main driver (see Figure 6.20).

> There are many parameters for us to name a place like the ocean or the sea, but the most important one is the soil that forms their border. The situation becomes complicated when we ignore soil and think of an immense body of water. In this new system, we thought about whether the conditions we are currently living on could be applied here.

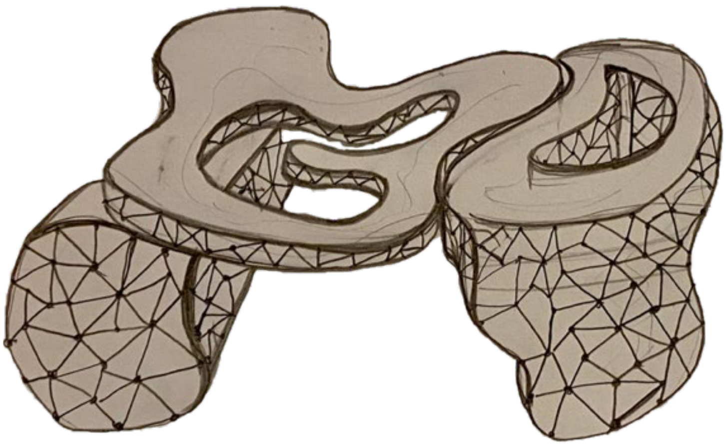


Figure 6.20 The Habitat Made of Reticulated Structures, G1

In G2 and G3's diegesis, the inclusion of novel habitats was comparatively scarce but apparent. Since they speculated on living styles, the diegesis they designed were carrying slight notions of novel habitats, such as in G2's diegesis, where transparent walls are present, or in G1's diegesis, where some of the humans are living in decentralised colonies in an environment where resources are scarce and hard to obtain.

6.2.2 Behaviour of the Living (Design Potential)

While designing their speculative materials, participants had to define behaviours for their materials. While defining behaviours for their living materials, participants benefited from the diverse behaviour of the living card deck. Despite being defined with a variety of living behaviours, the most prominent cards that emerged during the workshop were the temporality of living materials and assessing living materials as a resource with their behaviour of producing by-products. These two major themes could yield high potential for designers searching for design potential to design with living materials.

The temporality of living materials may be evaluated as the behaviour of the living. Nevertheless, since this was a speculative workshop, not every aspect regarding the behaviour of living materials was compiled under the temporality of living materials, especially since some of the behaviours are speculative to some members of living materials (e.g., hearing for microorganisms). Also, temporality does not holistically represent the livingness but may represent the livingness of microorganisms. So, while designing the workshop, the temporal qualities of living materials are defined under the behaviour of living with other speculative qualities. Based on the results, a clear separation between the temporality of living materials and using organisms as material resources became apparent in the workshop.

6.2.2.1 Temporality of Living Materials

As one of the most prominent inferences from my sensitisation activities and one of the most apparent sets of behaviours during the workshop, the temporality of living materials became apparent in my experience with living materials. As stated earlier in the thesis, it is also one of the main classifications made by Ertürkan et al. (2022) while creating a new vocabulary for living materials indicating the material's quality of change over time. Often considered for actual microorganisms apparent in the real world, even when the speculations and diegeses are involved, temporality remained important especially considering the communication between humans and living materials.

Reacting to Change and Communicating

Reacting to change was a notable theme while groups designed their speculative materials. The theme mainly emerged while groups were designing their material; however, it was also apparent while embodying the materials into products. On the other hand, the inclusion of the notion of *communication* is because all groups envisioned their materials reacting to change within human-living material communication. The communication here not only means communication in terms of showing the change in environmental circumstances, such as in the case of bioindicators, but it also means literal communication between the living material and humans.

Regarding G1's living material, they mentioned a secretion created by the living material, and they were hesitant during the process of whether their material is alive or dead and whether the secretion is alive or dead. They finished without defining a certain point for the livingness of their material; however, after analysing the in-group discussion and end discussions, they mentioned virgin areas where the material is not harvested. In those virgin areas, they state that their materials shape amorphous and uneven areas when the material is not touched by humans growing on its own, which we could understand that the secretion of the living organism is also alive. To explain it, they use an analogy from nature:

> We are in the city now; the soil is very little, and the intervention is as much as possible. However, when we go to a district, a village or a forest, the intervention there is as little as possible; either human hands do not touch it, or the damage we have done to the world indirectly recurs there, but we do not see such a significant impact. There is an indirect factor, such as climate change, but some areas can be defined as untouched as possible.

Regarding G2, since they mainly speculated on human communication and social construct, the changes in one of their living materials occur primarily for communication purposes. The material is reacting to changes in human actions, explicitly reacting to changes in the level of the *extremity* of human actions (see Figure 6.21).

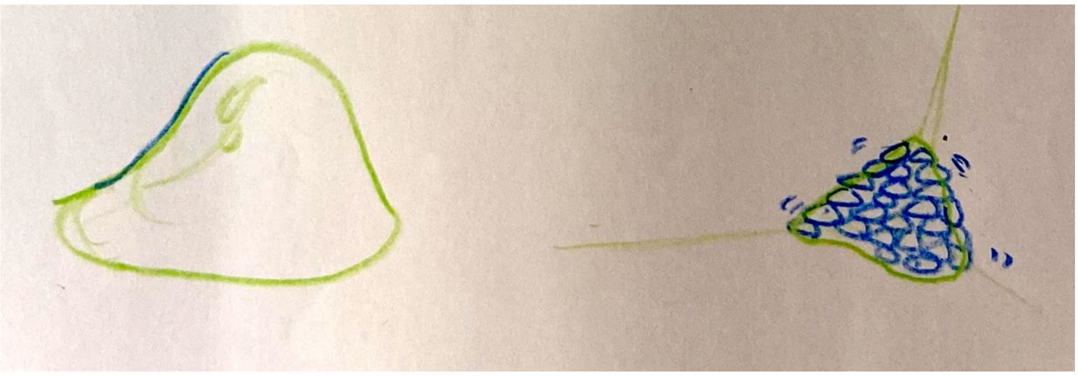


Figure 6.21 Living Material Reacting to Change, G1

This result is interesting not just in reacting to change but also in the multi-levelled structure of the action. 1) The human communicates with the living material through their actions, 2) the living material reacts to change, 3) the living material communicates back with its change, but it also communicates with the other humans (by making sound) consequently, 4) creates a communication between two different humans making the living material a *living communication interface:*

> When something extreme happens, when you are afraid or when there is a fight at home, etc., it hardens with that event and forms crusts on itself, and those crusts vibrate to the extent of the extreme situation, like a rattlesnake, chirping, making noise. People live in the house, and there, for example, they organise a party or people fight or have sex. Within the framework of these extreme events, the material hardens and starts to sound. Thus, that house starts to differ from other houses and attracts the attention of people walking on the street.

G3 designed their living organisms to react when the two organisms came together, and both the organisms react when they are present in water with specific mineral density or on the human skin (which has the same concentration as that water). In that respect, they react to environmental changes, becoming activated from their dormancy. The second living microorganism also reacts to the presence of the first microorganism, and it starts to reflect light providing invisibility when they are inhabited on human skin. Eventually, when the minerals and water are consumed on human skin, they become dormant again.

> When I spray, they need minerals and water, but there is only a certain amount of water and minerals in our bodies. When we bring them together with our bodies, that invisibility feature is activated again.

Changing States of Living Matter

This could be considered a sibling theme with reacting to change and communicating. However, the changing state of the livingness is not necessarily related to a reaction by the living material in the workshop, making this theme a present one. However, the findings I have explained in the earlier theme are also *changing states of living matter,* but the vice-versa does not apply. There were two emergent sub-themes while participants were discussing among themselves—first, the behaviour of *dying*, the physical state of the material, and its perception by senses.

All the groups discussed the issue of death, and it was also apparent during the presentation session. While discussing the living ethics during the presentation, death is discussed in terms of biodesign from a material biofabrication standpoint.

The participants asked whether it was okay to kill the material while speculating, and I explained it as a behaviour. Another discussion took place regarding what would be defined as *killing,* referencing fungi. P6 stated:

> If we are talking about fermentation in fungi, it is not killing. We stop their fermentation. It does not ferment anymore. I do not know if we should call it killing or not.

During the in-group discussions, the state of death is discussed within the groups in the context of usability. Only G3 used a notion of death for their living material; however, they were hesitant to call it death but preferred to define it as having a usage period or decaying. Nevertheless, it could also be interpreted as dying because they define a lifetime for their products embodied with living material. However, it is noteworthy to question the death of living materials and how they could be conceptualised ethically, especially considering their temporality. On the other hand, if not death per se but a behaviour close to death, G2 designed one of their materials to be decayed when exposed to artificial light providing a sticky feature:

> We imagined it like a plant; if the plant receives artificial light, some of its leaves deteriorate, and after that point, it provides a sticky feature.

Another aspect is the physical state of the living material. Due to the discursive nature of the method, the state of the living materials is defined with the aid of card decks related to living material design. While defining behaviours, needs and affordances for their materials, participants tried to visualise their materials embodied in products. However, the physical states of the material did not clarify by any of the groups. Instead, they are defined by using sensory features such as 'liquid', 'radiating', 'slimy', 'reflective', 'smelly' etc. and using colours' blue liquid' and 'green'. Changing states are defined based on the same features such as 'solidified', 'petrified', etc.

6.2.2.2 Organism as Material Resource

During the in-group discussions and outcomes, all the groups initially assessed their living materials as a 'real' material resource. For example, in G1, the boundaries between a material and a living organism initially could not be crossed because they had the idea of using the secretion of a living organism instead of an organism being the material itself. However, later, they evolved their material (the secretion) to be alive while defining specific living characteristics for their materials. However, despite the inclusion of livingness, it did not clarify in their anticipated UX phase because, consequently, their usage scenario (in the narrative) is shaped as if the material shaping the product is not alive; instead, it is a non-living material that we derive from an organism. On the other hand, while they were mentioning the affordance of their material, they described it as if it is a living one:

> We talked about motion. We talked about motion in terms of mimicking nature. Nature as being self-renewing and growing. A material that changes, transforms, and moves.

In G2, the other living material they designed was purely a material resource. A plant-like organism whose leaves decay when exposed to artificial light, showing sticky features like geckos' hands. A changing state of living material reacts to environmental changes, but the result (product) is utilised while the material is not in its living state. They stated: 'We harvest it and use the sticky, deteriorated parts.' In that case, the word 'harvest' carries importance because harvesting is often used for plants where livingness continues, but a part of the organism stays alive. Combined with intentional decaying, it could be interpreted as *pruning,* highlighting that *killing* does not necessarily have negative meanings.

The most prominent approach regarding assessing living material as a material resource was in G3's diegesis. Starting from drawing the *diamond batteries* card, they speculated a lot about their living organism, saying it produces a diamond-like stone for energy production (see Figure 6.22). An organism consumes certain minerals and produces diamonds or diamond-like material, progressing until they are introduced to the second and third stages. In those stages, they adapted their living organism to create a diamond-like material and included another organism conceptualised for human utilisation combined. Therefore, considering all the examples, I would like to underline that using livingness as a material resource yields potentials within and could be conceptualised when the organisms are not merely used but rather cohabitated in mutualistic relationships. If livingness became a prominent feature of products, sourcing something from them to produce something else could be a significant paradigm.

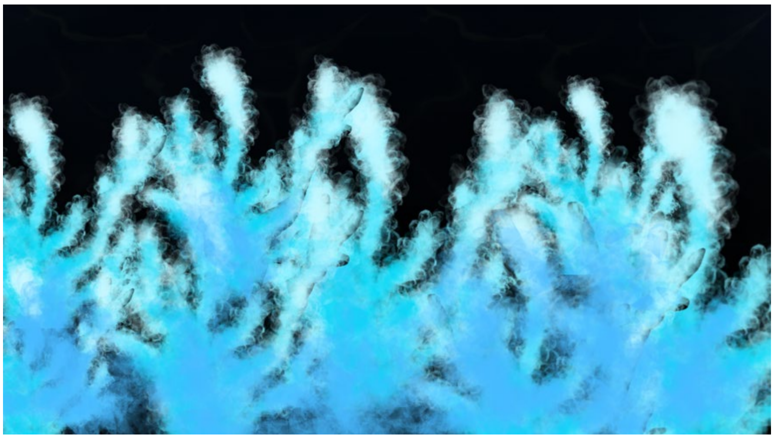


Figure 6.22 Diamond-Like Corals Discovered in Diegesis, G3

6.2.3 Living Needs (Design Criteria)

This was a major yet least dominant category consists of themes derived from the data, despite being one of the most prominent features of living materials, especially in the real world. The speculative nature of the method might have been over-dominant while speculating and defining needs for living materials. That mainly might have two reasons based on the data. First, addressing my experience from the sensitisation process, since understanding the needs of the material is a complex and time-consuming process with a lot of tinkering process, I might not have used diverse enough cards for the living needs to guide the participants. Because of the same reason, the specific requirements of each fictional organism might have been too complex for participants to come up with something prominent rather than noncommittal.

Second, since tinkering with living materials to understand their needs is a highly alien practice to designers, even I might have enough hands-on experience to speculate regarding a need of an organism. So, while designing those cards, the level of expected speculation could have been increased by defining needs not only specific to the physical requirements of organisms but also needs in multi-levelled aspects such as humanistic needs, psychological needs, etc. It shows the importance of including a briefing session regarding the needs of living materials or *understanding livingness* prior to the generative session. However, I did not want my participants to fixate on the hierarchy of topics and obstruct their imagination while speculating. Thus, the data shows an essential aspect of designing for the future of living materials: with a limited understanding or articulation of the living material, the diegesis tying the material to speculated environments, places or interactions will also be limited (e.g. less convincing, compelling, or inspirational). So, if such materials are to be contextualised within daily life in the future, designers must be properly aware of – or comprehensively define - the living material properties and needs.

Despite the statements above, the living needs designed during the generative session were diverse yet scarcely mentioned. However, they all shared a common notion: covering the living needs from the materials that could be found in and on humans.

6.2.3.1 Humans as Habitats

Appraising humans as habitats for living materials, all groups envisioned a mutual relationship between their material and humans. However, what is interesting is that none of the groups speculated other than directly being fed from the human body or organic reactions sourced from the human body except G2's second living material, which needs usual plant care.

G1 was hesitant to define specific needs and care actions for their materials; hence did not appear as a theme directly in their data. However, having the quality of 'spreading' with the increase in human number during the end discussion, they used 'like fungus/mould' in their description. In that case, despite not using specific care actions, these two notions concluded *a living material that needs human presence to grow and thrive*. Moreover, during the same discussions, while we were commenting collectively on their material, a dialogue between myself and the group took place:

> R: - If it expands as people multiply, maybe it lives inside people, or maybe something like a virus, but it can be harvested and collected.
>
> G1: - We thought it might be a microorganism in this respect. Even though it is a creature we did not prefer to define, these keywords and the results have always led us here. It is a microorganism.
>
> R: - Maybe even it is fed by the human body, or the breath feeds it. Because it seems like it is going to be such a concept.
>
> G1: - Yes, it needs to be fed. It is also a precious secretion; it is a precious species because it constitutes our life.

In G2, after they drew *extremes* card for the need of their living material, they interpreted extremes as if it is extreme events instead of extreme conditions (high temperature, high pressure, presence of high radiation etc.). Extremes that some living organisms need to live (extremophiles) or evolved to live (such as anglerfish that inhabit very deep underwater without any light). While considering the extremity, interpreting it as the extremity of humans, they came up with the idea of feeding on human adrenaline. While the extremity, hence human adrenaline, provides a feeding source for their living material, it also shapes their living material's behaviour. It was an exciting interpretation of the card and coherently connected to their diegesis. The adrenaline might be interpreted not in a tangible manner but rather like a pheromone that humans secrete outside their bodies. They described it as follows:

> This material needs extremes as a requirement. Could it be human behaviour? For example, when you do bungee jumping, you carry it with you, and it feeds on the adrenaline you release. We integrated it into our daily life later.

In G3, the relationship between humans is like G2's, but instead of leaving it undecided, they designed their material directly feeding on the minerals on human skin. However, since they had two living materials, which could inhabit the human skin, the reactions to match the organisms' need and human need is connected in a chain reaction. While an organism could create a novel material while feeding on human skin, the other organism would join them to make them change their appearance creating camouflage for humans (see Figure 6.23). In other words, human skin is assessed not just as a habitat but also as a *catalyst* for initiating reactions.

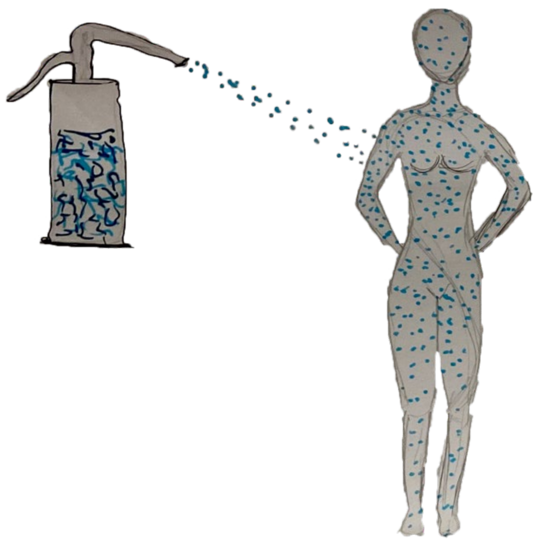


Figure 6.23 Spraying Microorganisms on Human Skin, G3

Considering the accounts above, regardless of their usage, all groups envisioned a future where living materials do not need extra caring actions but rather directly either inhabit or feed on the biological reactions in the human body. In that sense, despite rarely emerging in the data, the commonness of the theme makes it a powerful and clear one. Especially in creating and sustaining mutual relationships, the investigation of the human body specifically for these purposes could play a crucial role in creating sustainable relationships in the future.

6.2.4 Design and Interaction Possibilities with Living Materials

In the final phase of the generative session, it was expected that the participants embody their materials into products/infrastructures and consider the experiences around these materials, use scenarios etc. They were also expected to imagine care actions for their materials. Consequently, whilst the initial step is highly applied, the latter stage remained somewhat hidden since the living needs could not be defined because of the possible reasons I have listed in Section 6.2.3. On the other hand, while the groups were speculating about their living materials, the concept of 'material' and 'product' became intertwined, resulting in material-products rather than the embodiment of a specific material into specific products. That may be caused by fuzziness of the design fiction approach although it could be interpreted as an advantage to show the future of design tendencies of which materials are the products without the involvement of further technologies and other materials.

Regarding design and interaction possibilities with living materials, three major themes emerged. One is the function of living materials; the other is making with living materials; the third is design for sustainability with living materials. It could be understood from the sub-themes that the design and interaction possibility as a theme matches what is considered for conventional products. Here, I intend to present what is unique to living materials in terms of 'function and making' rather than handling the topic regarding everyday design concerns. Also, I would like to address the strength of design fiction, hence speculative design, to open up novel alternatives by allowing participants to create their interpretations during the generative session, resulting in diversity.

6.2.4.1 Function of Living Materials

As one of the material's potentials, the function of living materials emerged in the generative session. Apart from the functions of conventional materials, which are often related to physical properties, the combination of speculation and livingness offered novel and undiscovered potentials while participants were designing their living materials. The function here is not used as it is defined in a materials and design sense, but rather in how living materials could be situated within everyday contexts, defining function as a holistic definition for many aspects (e.g., form, affordance, experience) of materials. On the other, since the workshop's focus was on envisaging living materials from a discursive perspective, assessing a 'function' of a speculative living material would not be logical. Therefore, what is included here is the future of the *function of living materials in human life* rather than being material quality.

Living Materials as Social Facilitators

Since the social issues within the society were a prominent subject throughout the generative session, living materials are often contextualised in social situations where they are effective in human-to-human communication, human-to-living material communication and living material-to-living material communication. Moreover, social facilitation is not regarded considering only just the psychological meaning, which could be summarised as "*…the presence of another to ease individual's task*" ("Social Facilitation," 2022), but also in the meaning of creating novel social contexts where the living material is present. Therefore, the living materials were designed and contextualised during the workshop to facilitate and start *communication.*

In G1's diegesis, the effect of the dominancy of the social topics was so profound that during the generative session, they positioned their living material as a social facilitator situated in their diegesis, even starting from the initial discussions. First, in the earlier stages, they discussed the concept of *sharing* while considering the origin of their living material. Despite the idea being disregarded later, in the earlier stages, they mentioned sharing using an analogy from Turkish culture's fermentation of yoghurt and yoghurt-making. A spoonful of yoghurt culture, preserved from an earlier yoghurt, is added after boiling and resting raw milk to produce yoghurt, making the process infinite in theory. If the yoghurt is not being preserved before, it would not be possible to produce yoghurt without purchasing additional bacterial culture, which creates a notion of *asking a neighbour for yoghurt culture.*

In that sense, the data that emerged is quite interesting in tying an everyday cultural practice to a somewhat distant concept of *materials.* Also, a very concrete observation was made by G1, considering a sharing practice around living materials even in the everyday context. There, it could be seen that the cultural practices carry potential in terms of positioning living materials in a context. On the other hand, the living materials could be potential conversation starters and communication mediators if they are positioned within a 'share routine' supporting a cultural practice.

Later their living material went in another direction and has been imagined as a habitat for humans. In that case, they also connected the different physical states of their material (loose, tight, hard, rough, rugged, etc.) and the social practices. That could also be related to changing states of living materials as if they could become *tangible sensors* but matching it further with the social qualities of spaces could be influential while designing living materials in the future. In the end discussions, they stated:

> It is a flexible structure. When knitted more often, it becomes more rigid [addressing privacy]. When loosely knitted, there are more open spaces and porous structures [addressing public spaces]. That is why we once had conversations about the intersection of these public spaces. A public space where the material is loose, and the general area is much broader and flexible [for] being together.

The social aspects were also prominent in G2's discussions since they constructed their material directly relevant to communication practices. Especially one of their materials is a *communication asset;* the product shaped around the material is related to communication. Their material, hence, the product evolved in a way in which people could communicate through mimicking digital communication in the physical world and the living material inhabiting transparent walls is there to assure it (see Figure 6.24).

> We asked if we could use our material as a communication and expression medium. We thought these transparent walls could have a structure consisting of modular bricks. There are corridors inside the bricks, and since our living material likes to be hidden, we thought it would happily live there when we put it inside the bricks.

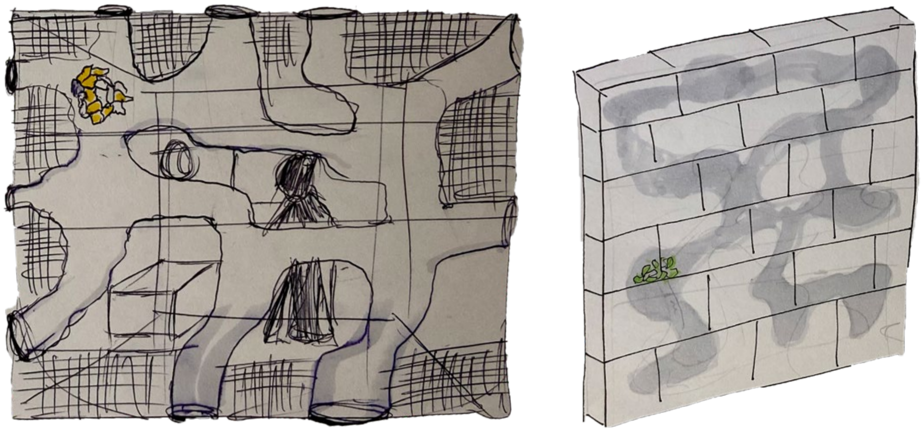


Figure 6.24 Transparent Walls with the Living Material Inside, G2

Living Materials as System and Infrastructure Designers

While discussing during the world-building phase, participants often speculated about a bigger picture while trying to define their Storyworlds. Since the nature of the first phase directed them towards speculations in terms of the appearance of the whole world and the mechanics to make it work, they tried to characterise certain qualities for their diegeses based on their selection of global challenges and opportunity cards. After that point, while G2 and G3 preferred to go where they could become focused in terms of contextualising designed artefacts within their diegesis, G1 preferred to follow a path in which speculations regarding the creation of more extensive systems are comparatively more possible.

Earlier explained in this chapter, assessing their living material as a replacement of soil, G1's entire diegesis and living material are based on infrastructures. However, such a result did not occur by chance. Instead, they started their discussion by taking *automated transportation* and *soil degradation* cards. From that point on, combining soil and transportation, they started to draw plans and sections and speculated on what it would be like to live underground. Since the emergence of living underground has strong connotations of novel habitats, they preferred to proceed to find a solution for alternative living spaces, even considering 'urbanisation', 'traffic', etc., underground. Despite the idea of habiting underground being disregarded later, the notion of novel habitat remained prominent in the later stages, resulting in their material being more than a new infrastructure system, a habitat, and a new world (See Figure 6.25).

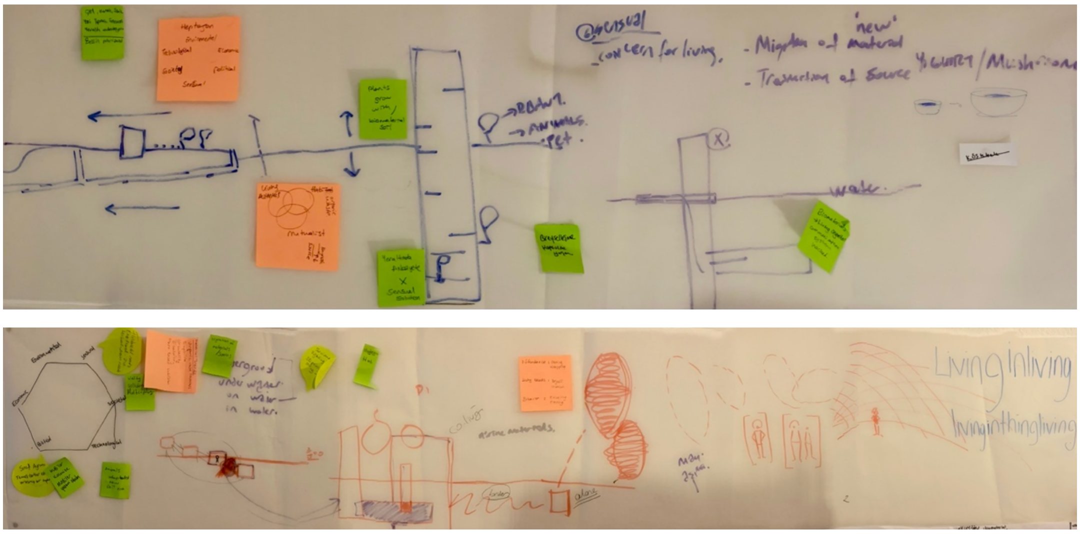


Figure 6.25 Drawings Produced During the Generative Session, G1

Using biomimicry as a primary driver in the following steps, they envisioned their novel habitat to be created in hubs like a 'cocoon.' While defining their living material/novel habitat, they stated:

> So, what we mean by the material here is a new city structure and system. We are talking about a module; we are talking about the material that makes up that module. Modularity in a sense, that is, I can live alone, but at the same time, I can be part of society. In other words, the material does not just wrap me; it expands and, with the manipulation, begins to wrap us.

What was also interesting in the data was that while they were speculating regarding creating systems, they mentioned the concepts such as 'hive-mind' and 'underground root networks.' So, for a while, instead of creating new networks and infrastructures, they discussed using the networks already created by other living beings underground, trying to mimic the natural systems already present. The idea of mimicking living systems later evolved to mimic nature as a whole and mimicked nature with living materials, resulting in *applying biomimicry using living materials*.

In G3, the topic of infrastructure emerged as a starting point in their discussion while speculating on energy systems. After they kept the issue of energy adapting it to the product level, they later focused solely on their material and kept energy and infrastructures as a minor part of their diegesis. In G2, the infrastructures were used as a complementary element while defining their product. Since the diegesis was based on transparency and transparent structures, they later assessed the unique quality of diegesis as a potential for product embodiment. Whilst G1 created the infrastructure with living, G2 created the living for infrastructures. In both cases, it is demonstrated that the living materials could play an essential role in creating the system and infrastructure scale applications and product scale ones, especially when looking at the nature to learn and the nature to make combined.

6.2.4.2 Making of/for/through Living Materials

Thinking about the embodiment of their living materials, the making of living materials emerged as a theme during the generative session. It is a category which is also proposed by Ertürkan et al. (2022) considering *"…the way of living materials is developed"* (p.15), and it is not a surprise for such a category to emerge in a generative session including a living material design phase. Since the two datasets differ and the scholars' work analysed the present data more holistically to create novel vocabulary, the data I will present here will be focused and does not share the same aim. Therefore, instead of broad coverage related to making living materials, I will explain the prominent sub-themes that emerged during the workshop. Namely, the sub-themes are the *processing of living materials* and the *technology of living materials.*

Processing of/for/through Living Materials

As a theme, the processing of living materials stands out for the operations carried out to either pre-process or post-process the living materials regardless of industrial connotations. Hence, it also includes the topics such as crafting with, hybridisation, activation and sourcing of living materials evaluating the term 'process' broadly.

Processes for living materials were a prominent subject starting from the presentation session. From the first approach, biodesign as material biofabrication standpoint, the processes to make something out of living material are questioned. Specifically, because of the visible borders between what a material is and what a 'living thing' is. Therefore, P2 asked:

> When we talk about living things, shall we think of this living thing as a resource when we say material? Or will we think about what the living thing will be like?

After, when group-discussing were taking place, the idea of processing the living material remained prominent in all groups, which considered various aspects of the processes that take place while designing with living materials.

Since G1's diegesis was mainly based on creating mutual relationships with living organisms for novel habitats and assessing their organism as a resource rather than the material itself, they predominantly included later processing their material to create novel habitats. The notions such as 'intermediate product', 'raw material' etc., were quite prominent when speculating. Later they thought of the concepts of *harvesting* and *crafting* and envisioned their material to be a processable secretion which humans could harvest and use to build their hubs by disregarding technology and including crafting (see Figure 2.26). Hence, they presented their material as an intermediate material initially secreted by living organisms and later crafted by humans into a different set of structural elements such as knits and panels. Consequently, they used their processed material without involving other materials for the hubs to create a structure which is resistant to water. While presenting, they stated:

> We envisage that when you ignore technology, we attach importance to designing living spaces by shaping the existing material without a second material. This secreted material went through some stages as an intermediate material and was transformed into panels after disinfection, drying etc. and thus transformed into a structure that can be knitted, forming the panels of these hubs that we are talking about, and it surrounds us in that way. It becomes a semi-finished product through some intermediate processes and is used as a unifying element in our concept design.

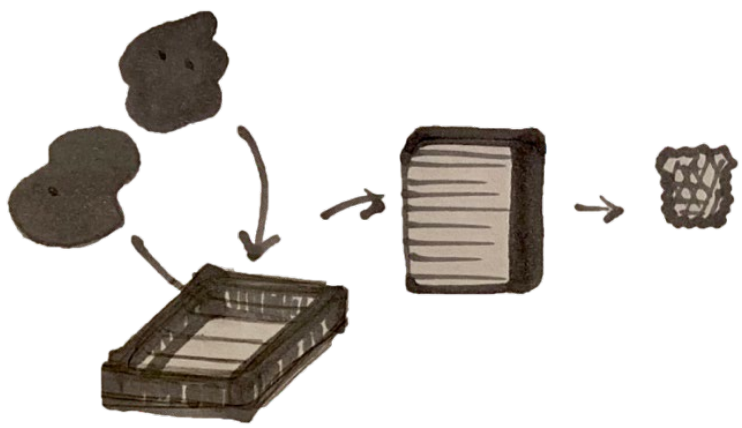


Figure 6.26 Processing the Secretion of Living Material, G1

In G2 and G3, consideration regarding processes of their living materials was comparatively less apparent but considered. G2 designed one of their materials to be living inside transparent walls reacting to change, as earlier explained in the previous sections. Also, G3 designed their material which needs a catalyst for reactions. In a sense, both groups need a process of activation for their living materials to be used, and both need a type of catalyst that takes place in humans to use their living materials. While G1 processed their material to use, G2 and G3 interpreted their processes to be carried out before using their material. In G2's case, the process took place for the secretion of adrenaline by humans, and in G3's case, it took place while providing the required minerals for living organisms. Also, during the end discussions, a dialogue took place by the participants who are not members of G2 considering pre-processing:

> P4: - When a person is sprayed, it is activated due to a reaction. Does it happen when it is sprayed on something else?
>
> G3: - No, nothing happens. The ratio of minerals and water on human skin makes it activated.
>
> P2: - Maybe we can do the same thing if we spray the same ratio of minerals and water on human skin on another object before.
>
> G3: - Exactly, it can evolve into anything. You could turn it into a cloud containing moisture and minerals and make it rain on top of something else. Nevertheless, we focused on one thing in the end.

Different ways of matching needs and post-processes could help assess living materials as a resource. From a perspective, it is rather present nowadays in the case of mycelium production, in which processing and needs could alter the living aesthetics. On the other hand, the processes to make use of living materials could take place without any further actions making them a regular part of daily life, like taking care of the bacteria living in our guts by only eating. In a sense, this could be a part of the answer to the questions regarding living ethics.

Technology of/for/through Living Materials

As would be expected from any design fiction workshop, technology was an essential driver in creating the diegeses and creating the products embodied by using living materials. Technology was one of the main subjects (environment, politics, society, economy) which groups had to define for their diegeses so much effort can be seen from the data. However, I will present only when technology is related to living materials during the generative session, but I would like to underline that technology was one of the most important subjects even during the presentation session. Therefore, the usage of technology concepts such as *blockchain, drones* etc., are left out of the theme as they are not connected to living materials.

Biotechnology emerged in every group's discussion. While speculating, the groups primarily focused on biotechnology, considering humans and living materials. As it could be understood from narratives, G1 and G3 referred explicitly as non-GMO species, and G2 left it blank, preferring not to define instead defining a high-tech, biotechnological diegesis. In parallel, due to the nature of the methodology, it would be illogical to expect them to consider such aspects of their living material, but G1 referred to their material as not a modified species and artificial but as natural as soil at the same time, creating questions in minds. As a theory, such hesitancy could be connected to ethical discussions since genetic modification would be connotated to negative meanings, highlighting the importance of ethical clarifications again.

On the contrary, as their world is comparatively more dystopic, or at least their living materials serve the dystopia instead of solving a problem within the diegesis, G3 probably envisioned their material to be innovated rather than explored. Then they felt 'bad' for it and 'pitied' their material while embodying it. There is no argument for the presence of technology in the future of living materials.

Human-computer interaction (HCI) was one of the two prominent technology-related subjects related to living materials. Apart from the involvement in the diegesis, as earlier explained, G2's material feed on human adrenaline but the living material and humans are separated. Other than the earlier interpretation of the living material sensing as if adrenaline is interpreted as a pheromone, it could also be interpreted as the wireless communication between a cyborg body and a living interface since body hacking and cyborgism is numerously featured during in-group discussions and mentioned in the end discussion. When adrenaline is produced, a piece of technology on the human body receives its signal and then sends it to the living material, making it activated as if it is a digital catalyst instead of a biological one.

While forming their diegesis, despite being discarded after, G3 discussed HCI in terms of creating intelligent artefacts with the help of living materials connecting the livingness of the human body to the livingness of living materials. They mentioned the living materials as if they could be *living codes* that could track human movement and memorise it or be 'thought' to do specific actions when used with the human body instead of conventional computational codes. This concept alone could yield much potential in the future of living material. Hence, as it matches the theme of humans as habitats, investigating human biology and the ecology of organisms to create novel technological applications could be an essential task for a designer in the future.

6.2.4.3 Design for Sustainability with Living Materials

The assessment of living materials or biodesign under DfS approaches is yet to be done. The usage of living materials is often referred to as a sustainable alternative method in terms of DfS, as explained in the literature review. Nevertheless, the participants speculated assessing the living materials as a tool to address problems in their diegeses. On the other hand, they considered some of the DfS approaches as a part of utilising living materials and products, but they could not assign such approaches for the sustainability of living materials. Despite only a few being directly related to living materials, the emergent sustainability strategies could be listed as *modularity, circularity, sharing, personalisation, upgradeability, biomimicry and biophilia.*

The reason why most of these strategies are not easily correlated to living materials could be questioned. These aspects are often considered from a human-centred design standpoint. So, they are also being considered as such by participants rather than thinking of the sustainability of living materials. Comparing it with the scarceness of the definition of living needs (which may be caused by the limitations I addressed) (see Section 6.2.3), the sustainability of living materials remained significantly less. Because of that, the DfS approaches may be inefficient to apply for both sides of the relationship, making a novel framework needed while designing with living materials considering sustainability. Whether the DfS strategies could easily be integrated into living materials should be questioned. Based on the data, these approaches remained weak in communicating with living materials and became additions instead of being placed in the centre. For example, all groups included some of the sustainability strategies thinking of the usage period from a human perspective, without considering the sustainability of their living material.

On the contrary, following a path to directly solve it or underlining the importance of it, all groups addressed the challenges in their world. That could also be evaluated under a sustainable approach to living materials regardless of DfS. For example, a mindset that focuses on SDG's instead of DfS. However, since the flow of the workshop led them to these challenges, it is vague to assess their outcomes whether solving a problem did influence them or whether the card decks directed them in such a way. Nevertheless, the effort to include sustainability remained prominent in their logic, if not in the sustainability of the living materials. Therefore, the ease of integration of such strategies and approaches to living materials could be a future challenge for designers.

On the other hand, the concepts of biomimicry and biophilia were easily related to living materials and included in the literature review chapter. That allowed the participants to develop designs that made them consider their living materials and influenced them while speculating and communicating among themselves. Biomimicry created the notion of 'including other living beings' in the design, referring to organisms in everyday life while designing their materials and defining care actions for them. It could be named as a form of combination because prior to the material design phase, for example, G1 often referred to the systems which other living beings had already created and tried to contextualise their living material within a biomimetic system to increase the well-being of their living material as well increasing the efficiency. In terms of biophilia, creating a connection with the dual well-being of living and humans, the same group envisioned a scenario where the material's condition could affect humans and vice-versa. By including these concepts in the outcomes and discussions, biomimicry and biophilia could help people effectively communicate for living materials and consider both sides of the relationship. Especially the notion of learning from nature could create novel ideas for living materials to be part of our lives as it could be enlightening in terms of conceptualising living behaviour regardless of what the living being is. Because mainly, despite often complex, specific behaviours and needs of living materials, looking at the ones we know before investigating the unknown could play an essential role in creating future mutual relationships.

6.3 Evaluation of the Workshop

Analysing the same datasets, I am going to briefly present the findings for the evaluation of the data collection and analysis method (workshop) that was designed and followed. Before that, I would like to start by acknowledging that, since I have carried out this workshop only once, the data emerging for the evaluation is intended to inform further development of the workshop (hence it carries the notion of 'self-critique') rather than a detailed research design evaluation per se. After the workshop, I asked participants to give feedback about the day considering each of the workshop steps that were covered. After their verbatim transcription, I analysed the critiques, combined with my observations on what happened during the generative session (see Figure 6.27).

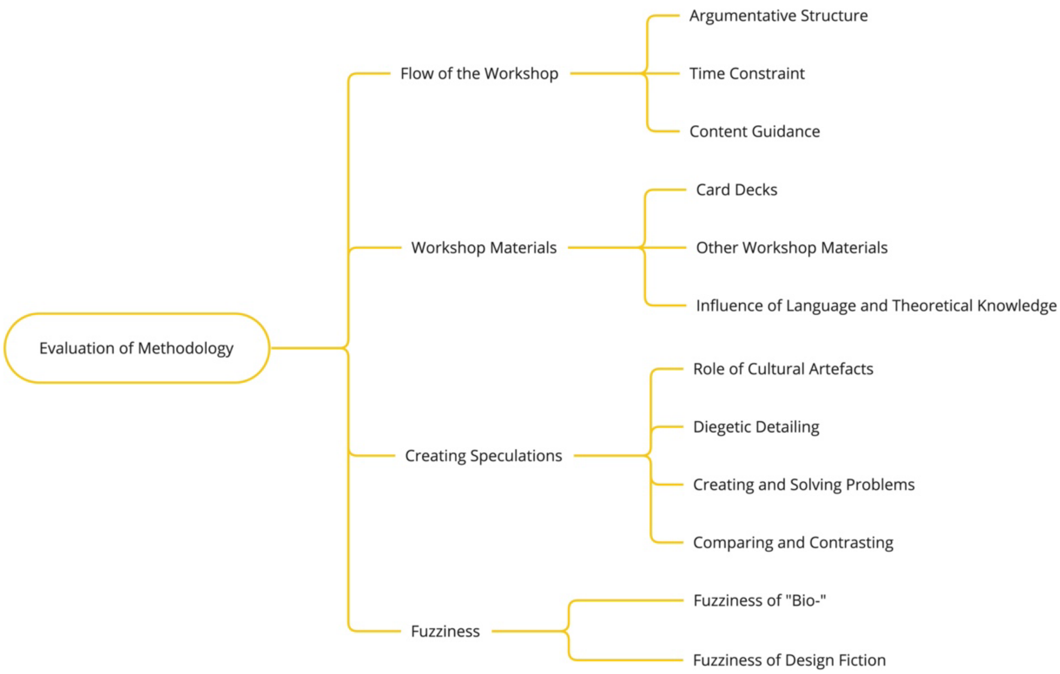


Figure 6.27 A Mind Map Including Major Themes and Sub-Themes of Evaluation of Workshop

The sub-themes emerged after the analysis results were compiled under four major themes, namely: 1) flow of the workshop; 2) workshop materials; 3) creating speculations; and 4) fuzziness. I am going to present these major themes briefly to understand what could be improved and how the efficiency of the workshop might be increased.

6.3.1 Flow of the Workshop

I would like to address this significant theme by starting with a sub-theme of *lack of methodological constraints and guidance*. Based on the data, it became apparent that difficulties controlling the participants and ensuring everyone was on the same track were prominent issues during the works. Despite this will be addressed later in the study's limitations, I would like to say that I carried out the workshop as the only researcher. Contrary to other data collection methods, such as interviews, the intensity of a generative session with multiple participants, facilitated by a lone researcher, is not something to be underestimated.

The critiques and discussions within the groups regarding the guidance primarily focused on the constraints in diverse subjects, such as 1) not applying the phases by setting deadlines to provide time constraints; 2) by not defining specific rules in terms of creating the content and speculations; and 3) not providing the limits to make the results consistent with each other.

Argumentative Structure

With the idea of not limiting the participants, the workshop might have been applied without providing enough rules. Especially as being one of the discursive areas in design, design fiction as a general approach comes with its cons which became apparent to me after the application. One such drawback is that while discussing the diegesis, the arguments tend to be endless because of the mysterious nature of the design for discourse action. Regarding this, P5 stated:

> We bent and twisted the first phase so much we flew somewhere; we went from there to here, and we couldn't recover.

Time Constraint

In line with discursiveness, since groups are overwhelmed to stop the discussions, not defining a time limit for each phase was criticized. The timeframe was set beforehand, as seen in Chapter 5. However, I was a bit hesitant to apply it meticulously. I preferred to guide participants with softer transitions, but it was not enough, since half of the participants commented on this issue. P5 also stated:

> I thought that phases should be time constrained. Because we extended the first phase in which we started with the first excitement and ended with lower energy in the third phase.

As an alternative to this matter, P2, P5 and P6 proposed completing some of the phases alone, separated from the group, which may lead to benefits that the design of the materials and products would be diverse and novel interpretations within the same diegesis could occur.

Content Guidance

Another issue related to constraints and guidance emerged within the scope of content creation. Because of the fuzziness, which I'll address later, while designing and creating their content, the participants felt too free to set a design framework for themselves, thinking that their speculations are endless. That could be assessed as one of the drawbacks of applying design fiction in a broad sense. Having pre-prepared diegeses might be helpful as a solution, because participants were not only challenged with defining certain physicality for their diegeses but also contextualizing their artefacts within those Storyworlds. Based on that, P1 stated:

> There could be question patterns. In the biomaterial design and product phase, for example, to fit the materials in our world, there could be must question, such as: What is the physical appearance of your product? How do you produce it? What are the other materials used? Also, defining the care action phase could be 'questionized.' When there are only keywords, we have over too much space resulting in constructing the material differently. For example, we focused more on the physical part, but G1 did not think about that part, and we didn't think about what they thought. I thought they might be more directing something like this for outputs.

As a self-critique to myself, I would holistically point out my use of language on the matter of constraints and guidance. During my interventions, I often used the notion of 'being free' to answer questions and fill in blank points both in the generative session and the other phases. In those cases, although there are rules and guidance in the workshop materials, verbal communication plays a more prominent role in conveying the message. My statements on ‘being free’ might have led the participants to obscurity sometimes. Therefore, regardless of my intention of setting the participants free to enhance creativity purely for positive aims, with such generative methods - if they are predominantly discursive - constraints and guidance should probably be meticulously applied.

6.3.2 Workshop Materials

To provide consistency and coherency during the workshop, I designed card decks, a tips brochure and a working sheet accompanied by the presentation in which details of each step are explained. The overall impression regarding workshop materials was quite positive despite some exceptions. I will address these issues under two sub-themes: card decks and other workshop materials. On the other hand, relating the matter to the previous theme, I will talk about another finding: the influence of language and theoretical knowledge on the workshop.

Card Decks

Card decks designed for the workshop received positive feedback after the generative session. Participants specifically stated that the card decks were a fun way of proceeding during the workshop and the act of ‘drawing’ made them feel more integrated and creative. Despite the fact that the card decks could be redrawn and reshuffled, taking ‘upside down’ cards from the decks created a ‘curiosity’ feature regardless of being able to redraw. Hence, participants wondered about the possibilities that novel cards may bring and all redrew cards a number of times, which made some of them occasionally confused since they were ‘too free’ to choose.

In terms of content creation, card decks created a basis for discussions. It had both positive and negative effects on the usage of the cards. In positive meanings, letting participants take cards repeatedly reduced the possibility of obstructing the creative process by not forcing them to fixate on the keywords on the cards. Second, being able to redraw all the cards created a guideline for participants because they used them as the directors of their discussions and creators for new arguments when they were stuck. So, in effect, participants could redraw endlessly from the card deck until they found something that resonated with them or that they thought they could make use of. On that issue, P5 stated:

> I think the cards were thought out very well. The limits it gave were reasonable, so we weren't supposed to be able to get out of it. I think they were very mind-opening. I like them, especially the affordances cards. We might not be able to do anything if it wasn't for our affordance card anyway.

In negative meanings, because of the total number of cards (n=254) within decks (n=9), the cards sometimes got mixed up during the generative session, despite them being colour coded. For example, when I was not present, G1 discussed the wrong card at the wrong stage for ten minutes until I intervened. Apart from the truth of having many decks, taking a card from the false deck could be interpreted as a common mistake or caused by limitations. On the other hand, the appearance of such discussions could allow me to trace it back to the overwhelming number of decks and cards. So, despite not mixing them up, the two groups got slightly confused in following the cards and what they included for which step. Another adverse effect was that the initial decision for me to have card decks in the first place was because the cards would help participants only when needed; hence, they were free to include any other keyword that seemed appropriate. However, the card decks gained so much attention and interest that they became the focal point of the workshop; even the participants felt down when they could not see what they imagined in the cards. Therefore, I had to announce that their additions of keywords, notions, concepts etc., are very much welcomed.

Another point is that cards were interpreted in a way I could not imagine while designing and compiling them. Therefore, not including any visuals could have been adequate for the diversity of meanings that may bring a divergent set of results. For example, as explained earlier, interpreting *moving* and *wrapping* as a 'social action' rather than a material quality, or interpreting *extremes* as ‘extreme human behaviour’ rather than an environmental state in which an organism survives, etc. On the contrary, these observations had a negative effect, which I will point out later in this section. But overall, card decks were much appreciated and praised generally. In a sense, everyone had their favourite decks, which they considered the most fun and/or valuable. In that case, the decks should be further evaluated regarding how they could affect the flow of the workshop and the content creation.

Other Workshop Materials

The other workshop materials (i.e., presentation, tips brochure, working sheet and data collection sheets) were used to assist the participants and me.

The presentation explained the theoretical background of the topics to the participants. It also gave birth to discussions without the focus of creating something, which made a valuable set of data and helped to understand participants’ perspectives on various matters and how it later shaped their creative process. In that regard, the only low point in the presentation was the inclusion of more discussions on ‘needs of the living’ (a hands-on session rather than a presentation slide would be more effective).

The directions and rules on the tips brochure and working sheet often remained overseen. Even going through the tips brochure after the initial presentation, the participants did not use it as something they could refer to. Instead, they preferred to ask me for the details, which they could not answer themselves. On the other hand, I duplicated some essential and milestone points on the working sheet to keep participants on the same and a consistent track. Yet, two groups did not use the worksheet at all, finding it too structured to work on and instead used either big blank sheets or the backside of the working sheet. Considering what I have explained so far regarding the workshop evaluation, it is understandable that participants felt a lack of guidance from time to time.

Data collection sheets could be eliminated from the data collection process altogether because they provided little insight into the strategies. This comment is based on the confusion that the sheets created for data collector participants, who seemed overwhelmed to make such documentation whilst also trying to focus creative energy making design fiction. Therefore, none of the data collectors-participants worked efficiently, and the task became an in-group task of reporting what they had done so far, which caused time-loss occasionally. For a future study, if there is to be such a role, the data collector should have only the role of collecting data and should not take part in the creative process. On the other hand, it sometimes helped participants to compile everything together (collectively). But considering the previous section (see Section 6.4.1), such effects could be provided with the inclusion of scattered requirements of answering specific questions, which could be dissolved amongst the creative process as it progresses, rather than data collection per se.

Influence of Language and Theoretical Knowledge

Despite reporting under the category of workshop materials, the issues related to language could also be evaluated under the theme of 'fuzziness.' Since it is a part of workshop materials, it is investigated here because while fuzziness could be an intentional choice for some situations, here, it is not deliberate but rather a natural limitation of the workshop. Fuelled by discussions, speculative design methods could be seen from earlier examples (see Section 5.3.1), including keywords to create an image of the speculator's mind. While designing, I have followed the same approach, and since the design terminology is predominantly English, I have developed the workshop in English, but facilitated in Turkish (since all of the participants were Turkish).

Despite participants' knowledge of the English language (of whom most are employed as Research Assistants and/or gained their bachelor's degree in 100% English curricula), some keywords and terms could not be easily understood, which may be caused by their specificity. That resulted in a time loss occasionally for some groups during the workshop while they were trying to understand what the keywords meant. Since there were 254 different keywords, the frequency of such occurrences was worthy of reporting. Being a workshop that intends to create discourse with written data, it could have been a more time-efficient process if the participants knew the more profound theoretical-specific terms or if I had designed the workshop in Turkish. But, acknowledging the lack of exact translations and the positive impact of fuzziness in the creative process (even in language fuzziness), it could also be evaluated as a positive aspect, despite the time losses involved.

6.3.3 Creating Speculations

To create speculations, participants followed specific *strategies* during the generative session. Despite referring to them as strategies, the sub-themes listed below could also be considered as usual paths of a thinking process that could emerge while speculating in a design fiction workshop. Such strategies could have the ability to increase the efficiency and effectiveness of any design fiction workshop since they present an overall picture for creating speculations in design fiction rather than biodesign fiction per se. Hence, considering the sub-themes given below could be beneficial for evaluating the method. They are: *the role of cultural artefacts*, *diegetic detailing*, *creating and solving problems* and *comparing and contrasting*.

The Role of Cultural Artefacts

The effect of cultural artefacts was prominent during the workshop while participants were speculating. Cultural artefacts are defined as *"…anything created by humans which gives information about the culture of its creator and users"* ("Cultural Artifact", 2022). Bleecker (2009) says that fiction can influence design fiction, and the opposite also applies. In this case, mainly assessing films, literature and video games and designs as cultural artefacts, such artefacts were helpful for participants to enhance their creative thinking and communication (see Figure 6.28), which often emerged in the data. Especially the science fiction references were quite prominent while participants were creating their speculations.

Figure 6.28 A Diegetic Prototype Influenced from a Dress Made of Fabrican Fibres, Designed by Coperni (vogue.co.uk/fashion/article/coperni-ss23), G3

Based on the various occurrences of this theme in different phases of the workshop, including science fiction could be beneficial for such workshops mainly from two aspects. First, it could be helpful for participants to create an image in their minds easing the communication because the narrative-based thinking during the workshop refrained participants from telling the visual in their head, especially to other group members. Second, giving such examples provided the visualisation of the discourse for everyone, if not in reality, then cognitively, since everyone had their own vision of a cultural artefact. The inclusion of Midjourney AI was therefore included as a means to visualize the diegesis with the same kind of intention in mind. Allowing a third-party, unbiased (in terms of the workshop's participants) software to create images was considered helpful in creating further discourse and asking more questions, adding another level to interpretation and outside communication, which was one of the workshop's aims.

Diegetic Detailing

Starting from a broader perspective (world-building) and then creating entry points to diegesis (materials, followed by products), the participants were led to follow such a strategy in the workshop by the design of the workshop. It became apparent that the strategy of making participants follow such a road is an efficient way of creating possibilities for further speculations, resulting in diverse discourse.

On the other hand, diegetic detailing, especially diegetic prototyping, has been interpreted slightly differently because of the participants' time limit. Therefore, acknowledging limitations, the workshop could have been organised on two consecutive days for which participants further detail the artefacts contained in their diegesis. Then they could create products in which further details are included, such as how the living materials are produced, how they could be marketed, etc., which is also featured in P1's comments (see Section 6.3.1, Content Guidance). In effect, this acknowledges that the application of design fiction to the area of living materials requires considerable sensitisation by the participants themselves, followed by a relatively lengthy process to reach convincing and comprehensive descriptions of fictional living materials alongside the future worlds in which those materials are imagined to exist.

Creating and Solving Problems

All the participants, who are all industrial designers (six) and architects (three), thought solving problems was a fundamental task within the workshop. Despite including the challenges deck in the world-building phase, the reflex of problem-solving did not disappear in the following stages. That could be a guide for evaluating the workshop, since almost all of the participants acted as 'problem solvers' except for only one participant who adopted comparatively more of a ‘dreamer’ role. That could also be the main reason behind the sometimes excessively strong connection between the diegesis and the living materials and products. Significantly, no group thought in a way that the problems in the Storyworld could be adjacent to, but ultimately separable from, the envisaged living materials and products.

I would also like to address myself and how I designed the workshop. While creating the workshop, I might have been influenced by the conventional role of ‘solving problems’ and led the participants where the problems are the ultimate goal to be approached. Therefore, when the strength of the world-building phase is considered, the outcomes resulted in a way where world-building was ultimately quite prominent. However, it could be designed in a way where problems are not included. Addressing the literature and my mindset during the whole thesis-writing process, as well as the research questions, the prominence of the idea of assessing biodesign and living materials as novel ‘problem solvers’ did direct me in such a way. Therefore, I would like to acknowledge that without considering these paradigms as problem solvers, the workshop would have resulted differently – since the difference between whether I directed my participants to solve problems or whether the participants chose a way to solve problems could be separated. Consequently, another workshop could be helpful to specifically assess if the participants conceive living materials as opportunities (or not) for solving problems.

Comparing and Contrasting

During the workshop, comparison created a way for participants to enrich their speculations. Such comparisons mainly occurred while participants were contrasting their creations with what occurs in real life. Also, thinking of the ‘anti-’ to their speculations helped them in a way to make further speculation, creating new doors for further speculations. One of the discussions during the end presentations took place as follows:

> P4: - This permeable one is based on the current world and says the opposite. Now I am trying to make my voice heard. You talk about being visible on

> social media, popular, and famous. This system is something that carries it to the physical environment from the online environment. So, this logic takes it as a basis and brings something that does not exist to the physical.
>
> G2: - Yes. For example, in privacy, this invasion is already happening digitally. After that, when we asked how this physical reflection would be, we went in such a direction.
>
> P4: - Actually, you got the opposite. Because I'm social at the keyboard, but I can't leave the house. I'm home this time, though?
>
> G2: - Yes, it's very contradictory, actually dystopian on the one hand.

That being the case, intentionally increasing the number of such occurrences during the workshop could help participants come up with more diverse ideas. Despite not including such a way of questioning in the workshop design, the theme of comparing and contrasting was prominent in every group's discussion to find their way. Therefore, it could be a helpful strategy in such workshops for participants to lead them to think of the opposite of an idea, especially when they are stuck.

6.3.4 Fuzziness

A fuzzy concept is a concept in which meanings could change based on the context instead of having common meanings (Haack, 1996). I will address fuzziness in various sub-themes that emerged in the workshop. The logic behind including fuzziness is that it appeared to be one of the most robust results from the analysed data. It would be helpful to look at the nature of biodesign or living materials and design fiction to see the reason behind the emergence of such a theme. Maybe also to the biodesign fiction, where things could get even fuzzier.

As one of my sensitising concepts for which I conducted a field trip, the fuzziness of biodesign is also addressed in the literature (see Section 2.4.1). Therefore, considering my sampling group, my effort to reduce my fuzziness and the lack of definitions regarding the paradigm, the level of fuzziness of biodesign (and hence for living materials in the workshop) was high. On the other hand, as an emergent field, design fiction cannot be considered one of the most defined research approaches to date, which in turn is one of its strengths (it leads to provocation and discourse). Furthermore, the nature of the method could be named as one of the methods in which intentional fuzziness is appreciated for further speculations.

Not attaining any negative or positive meanings, combining these two fuzzy paradigms (design fiction and biodesign) caused the discussions within groups and the outcomes to be ambiguous during the workshop. From a broader perspective, it caused the results to be interpreted from many aspects but also to be narrative-based, argumentative and 'fuzzy' rather than providing clear insight into the future of living materials. Therefore, I would like to address this issue under two sub-themes: the fuzziness of 'bio-' and the fuzziness of design fiction.

Fuzziness of "Bio-"

During my earlier effort in defining the 'bio-' prefix from a design perspective, I concluded that the usage of bio is still fuzzy without clarifying its intentionality. Especially during the initial presentation session and while participants communicated within the groups, it was visible that the participants were often confused while addressing living materials whether they were 'biobased materials', 'biomaterials', 'biodesigned' or making use of 'biomimicry'. Apart from that, these situations occurred while participants discussed the constitution of what makes something living and something a material. Also, when the ethical considerations came forth, the same happened for the relationship between the death of living material and biodesign.

Here again, regardless of the benefits of fuzziness, which creates possibilities for different interpretations and outcomes, the issue of fuzziness could create more significant problems or direct misunderstandings if I had planned a workshop that did not use design fiction but instead focused on more concrete, evidence-based ideation. As I also addressed in the literature review chapter, the data shows a need for a clear understanding of what biodesign is and an evident diversification of what is designed with living materials compared to other bio-inspired approaches. That may not be an issue for methods that aim to find novel interpretations (such as design fiction), but it could create obstacles for designers and researchers wanting to understand the unexplored design possibilities of living materials and approach them from a more practical here-and-now perspective.

Fuzziness of Design Fiction

The level of speculation in the workshop was a consideration point even in the initial presentation session during the workshop. The main reason is that the design tasks, often connected to real-world problems, are stretched while creating speculations. Therefore, it becomes the designer's responsibility to control whether their speculations are becoming solely fiction or staying within the indistinct boundaries of design fiction. Since there is no straightforward approach to this issue, a certain level of vagueness of the method becomes a challenge for participants while speculating, and also for the researcher while designing and analysing. Such a situation did not appear just in this workshop but also in my prior experiences regarding design fiction.

The theme of the inherent fuzziness of design fiction underlines the importance of a robust framework for applying design fiction, which is still undergoing a developmental phase. Because of the contrast of adopting the idea of 'not restricting participant's imagination' and the notion of 'controlling the level of speculations by limiting them', the research design task is challenging. As it emerged in participants' minds as well, despite proposing an efficient set of tools for 'thinking without limitations,' it became an essential point for everyone unfamiliar with designing fiction since there is a slim line between design fiction and fiction.

For example, the over-prominence of the world-building phase had a knock-on effect that participants got lost in the diegesis from time to time, for which participants tried so hard to make logical. That may have been prevented by me while designing the workshop by including specific years (settings) for their diegeses; however, by not 'refraining the imagination' in mind, I did prefer to leave such directions out. But, some tangible features, which sometimes connected the participants to the real world in the workshop, such as including *material affordances* cards, were quite helpful. Therefore, it is essential to highlight the inclusion of certain elements to create the boundary between 'fantasy' (generated unbounded) and 'design fiction' (generated within guiding constraints) in such workshops.

6.4 Summary

This chapter initially introduced the emergent narratives, which I have reorganised based on the participants' in-group discussions during the generative phases and their descriptions during the end presentations. The disorganised statements that emerged during the whole day were gathered to create coherent narratives. Visuals generated by Midjourney AI were generated to accompany the narratives. The narratives produced by me, and visuals produced by the AI tool, are presented as complementary sources that could introduce G1-G3's storyworlds with ease, preparing the reader for the detailed analyses to come. Despite a few visuals produced by participants, the results were primarily text-based and communicated verbally; therefore, such an approach is also preferred to bring a visual domain to the results.

The chapter explored the first two aspects of the analysis that emerged during the workshop through thematic analysis. Namely, discovering the future of living materials and evaluation of the method are explained. In the first dataset, the emanant sub-themes are first positioned under the major themes and further categorised under the categorisation that emerged in the sensitisation and design phases. The categories (in bold) and the major themes (in italic) are as follows:

I. **Human concepts**: *human traits* and *human needs*.
II. **Behaviour of the living**: *temporality of living materials* and *organism as material resource*
III. **Living needs**: *humans as habitats*

IV. **Design and interaction possibilities**: *function of living materials*, *making of/for/through living materials* and *design for sustainability with living materials*.

Human traits and human needs primarily define the human concepts category. Regarding human traits, the participants elaborated mainly on the general notion of understanding livingness, considering the ethical and empathetic aspects and their possible role in social construct, as well as effects on politics. In line with that, the sub-themes match human needs by considering living materials as an aspect of emotional and physical well-being, human communication, and future novel habitats.

Under the behaviour of the living category, the major themes are the temporality of living materials and organisms as material resources. Whilst temporality of living materials occurs in reference to how an organism reacts to and communicates changing states, assessing an organism as a material resource is explained under the major theme without subsequent ones. On the other hand, under the category of living needs, mutual relationships embodied in the human body, or humans as habitats, was the only major theme.

Regarding the design and interaction possibilities, participants emphasised living materials in terms of function, envisioning them as the social facilitators and system and infrastructure designers. Also, in the making of/for/through living materials theme, processes to cohabit with living materials and the role of technology in that cohabitation appeared as the most prominent sub-themes. Besides those two major themes, sustainability is considered necessary while designing with living materials. However, instead of the prominence of DfS, the sustainability issue is handled from a ‘problem-solving’ perspective.

The evaluation of the method is also carried out with the intention of further development. Thematic analysis is used for analysing this perspective. However, rather than categories, the data was compiled under four major themes (in bold) and 12 sub-themes (in italic), below.

I. **Flow of the workshop**: *argumentative structure, time constraint,* and *content guidance.*
II. **Workshop materials**: *card decks*, *other workshop materials,* and *influence of language and theoretical knowledge.*
III. **Creating speculations**: *role of cultural artefacts*; *diegetic detailing*; *creating and solving problems* and *comparing and contrasting*.
IV. **Fuzziness**: *fuzziness of 'bio-',* and *fuzziness of design fiction*

CHAPTER 7

DISCUSSION AND CONCLUSIONS

The final chapter of the thesis discloses the study's discussion and conclusions. It begins with an overview of the study and proceeds to revisit the research questions. After that, the discussions that emerged from the analysis of the generative session are presented regarding discovering futures of living materials and evaluating the workshop, taking into account the sensitisation process and the respective literature. Lastly, the chapter explains the research limitations and suggestions for further study.

7.1 Overview of the Study

The study aims to investigate the future of designing with living artefacts using design fiction methods by exploring the possible speculative experiential potentials, cohabitation possibilities, practices, and attitudes when we switch from inert products and infrastructure to biologically alive replacements.

The relevant literature review (see Chapter 2) is explained in detail to achieve this aim which is organised in a manner that starts from general and ends specifically. First, a changing perspective of industrial design towards materials is featured by explaining the emerging material-focused design fields such as Materials Experience (Section 2.1.2), Material Driven Design (Section 2.1.3), and DIY-Materials (Section 2.1.4). The emergence of such approaches led to the formation of a new role, namely *material designers,* of which designers become active members of the material creation process. Also, the issue of sustainability regarding both DfS and approaching complex problems (SDGs) is explained concerning materials and design, which is considered one of the main drivers for designers to be interested in materials.

Then, the literature review shifts its scope by focusing on the 'bio-' approaches in design related to (not limited to) materials with sustainability in mind. Connected to, yet separate from, precedent approaches involving 'biology' such as *biomimicry*, *biophilia* and *circular design* (see Section 2.3), it focuses on the emerging paradigm of biodesign where livingness is essential during the production process or in the finished work integrating biology directly. Despite the term still being fuzzy, two approaches to appraising the livingness of an organism become apparent: first, assessing livingness as a feature to biofabricate materials and second, prolonging livingness to the use phase of artefacts. 'Biodesign as material biofabrication' was featured as the earlier approach (due to its emanation in academic literature and market) in the literature review. It is an approach where livingness is considered to take place mainly during the production phase of artefacts.

On the other hand, the 'living artefacts as biodesign approach' aims to prolong livingness to the use phase of artefacts, requiring discovery of cohabitation possibilities. After explaining the approaches and adopting a combination, a gap is positioned. It is the lack of empirical study on the future of living materials when design fiction (for biodesign, referred to as biodesign fiction, see Section 2.4.1.4) is applied as a research tool to investigate the future of the second approach (cohabitation possibilities with living materials).

Based on the gap and to answer the research questions, the methodological approaches and research design are explained in detail. The empirical research was conducted in consecutive stages to accomplish this goal and answer the research question. As a result, the empirical study was designed following a sensitisation process, and the sensitisation process and relevant literature influenced it. The chapter presented the methodological grounding of the sensitisation process and empirical data collection and analysis of the workshop. After the sensitisation process, the methodological approach was based on participatory action research

(Ritchie et al., 2013); more specifically, a *research through design* and *research through design fiction* approach is pursued (see Section 3.5).

Before the empirical study took place, a sensitisation process was carried out. Framing that process as a personal endeavour, it had a significant impact on the thesis journey, being a practice-oriented post-secondary research that assisted in sensitising on specific concepts such as biodesign and living materials. With that goal in mind, a biodesign lab was visited to learn more about working with living materials and discussions were held with researchers about practical details that could be hard to learn from reading alone. After the sensitisation process, the workshop design chapter described the workshop's design process. It summarised how doing research is correlated to doing design. The workshop flow, mechanics and creation of visuals are then explained in detail.

The analysis chapter first introduced the emergent narratives, which are reorganised based on the group discussions during the generative phases and the descriptions at the end of the workshop. In addition to the narratives, Midjourney AI-generated images were included (see Section 3.5.5.2). Through thematic analysis, the chapter examined the first two aspects of the analysis that surfaced during the workshop (see Section 3.5.5.1). The future of living materials was the first primary dataset. The dataset's major themes are listed first, followed by the emanant sub-themes, which are then further categorised according to the categories that emerged during the sensitisation and design phases. For the second of two, the method is evaluated to develop it further, and the data was compiled under four major themes and twelve sub-themes.

7.2 Discussion on the Research Journey

Based on the literature review, biodesign and working with living materials are becoming prominent design paradigms in the 21st century (Karana et al., 2020, Myers, 2012). However, designers are often unequipped to work with living materials due to the infancy of the field, lack of facilities and methodological frameworks (Karana et al., 2019). Despite a growing number of designers focusing on design approaches on materials such as MX, MDD and DIY Materials, working with living materials stays within the boundaries of niche requirements, often related to real-world restrictions (e.g., finding collaborations, finding facilities, etc.). Moreover, biodesign and the definition of 'designing with living material' are still fuzzy (Grushkin, 2021). While a certain level of fuzziness could be advantageous for designers (Grushkin, 2021), it could alienate the area even for design professionals, let alone design students. Therefore, the area calls for a definition and broader common ground to raise designers' interest in the field. On the other hand, biodesign and designing with living materials are also booming regardless of such limitations, primarily because of the sustainability-driven nature of the area (Camere & Karana, 2018a; Myers, 2012) and the increasing interest in more-than-human design activities (Coulton & Lindley, 2019; Giaccardi & Redström, 2020; Karana et al., 2020). For these reasons, a new framework becomes crucial for the ones who cannot directly reach out to, or be involved with, living materials but as compensation would like to produce ideas on working with such materials and their embodiment in artefacts.

Apart from the accounts above, the developing and evolving understanding of biodesign is putting the field in need of novel research and adaptations based on emerging changes in the theory and approach. Broadening the scope of biodesign from material biofabrication (Camere & Karana, 2018a;) to include conceptualising livingness for products (Karana et al., 2020) highlighted the need for new approaches. Comparatively recent, the second approach investigated what is already applied, and scholars created a framework for working with actual living materials, creating an outline for designers to *tinker* with and create novel material experiences with them (Karana et al., 2020). However, developing technologies in making and production techniques, combined with the developments in biotechnology, make the second livingness approach even more unexplored and ambiguous compared to the first livingness approach, especially when practical limitations mentioned in the previous paragraph are considered. Besides that, one of the categories under the first approach, biodesign fiction, is not just a scarcely investigated area but also is not investigated when combined with or utilised for investigating the second approach with cohabiting in mind. Therefore, it becomes apparent that investigating the future of designing with living artefacts could propose novel findings. Being influenced by biodesign fiction and adopting *research through design* and *research through design fiction* approaches with limitations in mind, a tool for designers to freely think without real-world boundaries becomes valuable for investigating the cohabitation possibilities and future of living materials.

7.3 Main Conclusions

The study's main goal was to discover the possible futures with living materials when they are situated in everyday life. After reviewing the respective literature, it became apparent that the second livingness approach (living artefact as biodesign) is not thoroughly investigated in the future context. Moreover, this area of biodesign has stayed within the boundaries of practicality and concrete applications, making it harder to investigate designers' perspectives on the matter when usual practical concerns of applications (such as tinkering with the living material, production processes, suitable facilities etc.) are taken out of the picture. Also, evaluating the fuzziness of biodesign (Grushkin, 2021) as a strength, the paradigm proposed a 'possible discourse' to be applied within speculative areas of design. Therefore, adopting a *research through design fiction* approach (Blythe, 2014), the future design possibilities and the visions of designers when we cohabit with the living materials are explored through the empirical study of this research. Based on those accounts, the main research question is formulated as follows:

- *How may the properties of living materials be applied in the future to improve the experience and/or functional features of product designs?*

The following steps are pursued to answer the research question: a sensitisation process in a field trip is completed (Phase I); a design fiction workshop (generative session) within the specific focus of biodesign and designing with living materials is designed (Phase II), followed by application of the workshop with design graduates (architects and industrial designers); and analysis and presentation of the results (Phase III). This thesis reaches two sets of main conclusions based on the work covered. The conclusions centre on: first, discovering possible futures with living materials, and second evaluating the workshop as a tool to generate Biofutures.

7.3.1 The Future with Living Materials

Based on the empirical study, it is affirmed that the future context with living materials will be complex and needs to be handled from various perspectives. It is also revealed that the future in which we cohabit with living materials should be approached considering both ends of the mutual relationships. Consequently, the study outlines four main conclusions, which will be addressed in depth regarding envisioning the future with living materials when humans cohabit.

Human Side of Mutual Relationships

As has been discussed in Karana et al.'s (2020) article, the human side of relationships is an essential topic for the emergence of relationships. Especially noted under the "*mutualistic care*" (p. 46) and "*habitabilities*" (p. 48) topics, in order to situate a living material in humans' life, consideration from both ends is essential. However, the article, which investigates the *applied biodesign* examples, handles the topic to create a framework for novel applications; hence the scope stays mainly on the organisms' side of the relationship and how to embody products considering the needs of living materials.

On the other hand, adding to Karana et al.'s (2020) article, **the human side of mutual relationships stands out as one of the most prominent aspects (as much as livingness) in terms of maintaining these relationships and making them**

sustainable. When living materials are situated within everyday life, focusing mostly on the needs of the living organisms will not lead to strong relationships. Based on the data from the generative session, the mutual relationships could be evaluated as direct relationships where organisms either inhabit humans or feed on humans without extra activities to maintain livingness. Therefore, it draws pictures of futures which point out the importance of 'naturalness' and/or the 'spontaneity' of mutual relationships to make them sustainable.

Temporality of Living Materials for Communication

Based on the data and the literature, it is confirmed that the temporality of living materials is an essential aspect of a living being's qualities (see Section 4.1.3, Ertürkan et al., 2022, Karana et al., 2020) while designing for/with/of living materials. Also, it is featured explicitly in Karana et al. (2020) as one of the three major topics under the notion of "*living aesthetics*" (p. 45). Besides being listed as a crucial living aspect in literature, it has also been addressed by the researchers talking about living materials and observed in the biodesign lab during the sensitisation process. The empirical study emphasises that it will be an essential feature while designing living materials in the future, as in today.

However, **beyond the conclusions derived from the literature and sensitisation process, a prominent aspect of the design potential of living material's temporality was based on the act of change and the communication possibilities through that change.** Since the issue of temporality concerning communication was extra-prominent during the data analysis phase, it became one of the significant conclusions for this study. Therefore, considering Jakobson's theory of verbal communications (Jakobson, 1961), the potential communicative interactions between different combinations of the *sender, message and receiver* became evident in conceptualising living materials (such as different triad combinations between human, organism, and computer). Beyond and in relation to that, the study shows that the future of living materials could propose novel undiscovered potentials in communication practices and necessitate a particular semiotic and semantic investigation of living materials for both today and tomorrow.

Understanding the Livingness as a Whole

The more-than-human turn is becoming a prominent approach to 'understanding' in design for natural (other than human) and artificial beings (Giaccardi & Redström, 2020). Living materials are included under the scope of this approach as being one of the 'natural beings' (Karana et al., 2020). Also, scholars and designers who are debating on the inclusion of living beings in the design process in terms of ethics and anthropocentric approaches are highlighting the importance of understanding the organisms by attributing importance to their livingness (Keune, 2021) and their rights to be equal, making multispecies philosophy a robust approach while including other than humans in the design (Westerlaken, 2020).

As it became apparent in the study, the issue of understanding the living materials, hence organisms, holistically and in-depth remains one of the most critical aspects to creating these relationships in the first place. However, **it does not only mean understanding the living qualities as they relate to products but also understanding the 'living materials' as they are like any other organism in nature, regardless of their level of development or prevalence in human life.** In the workshop, consideration of such attributes kept its prominence and was a *hot topic* during each phase. Therefore, based on the study, designers working with living materials need further ethical justifications to become interested in biodesign initially. Instead of biodesign focusing only on *how to work* with the organisms, the need for biodesign theory that either clarifies or discusses such issues becomes visible.

Sustainable Making of Livingness

Technological integrations are present in biodesign at the artefact and cell levels. Although most of them were focused on "digital biofabrication" of/with/for living materials (Camere & Karana, 2017, 2018a), the conceptual examples, including technology in which livingness is included in the use phase, is also present. For example, plants (Poupyrev et al., 2012; Seo et al., 2015; van Oers, 2016), animals (Costa et al., 2018; Oxman et al., 2014) and microorganisms (Smith et al., 2020). Besides technology-driven approaches, the crafting and manual making of living materials is also a usual practice. Using living materials for material biofabrication is a hands-on, exploratory practice that requires careful crafting with organisms (Camere & Karana, 2017, 2018a). Explored under the topic of "*growing design*" (p. 572), the scholars outline manual making and production practices around living materials (Camere & Karana, 2018). Therefore, as featured in the literature for the present, this research promotes that **adapting living materials to existing or developing technologies could create novel interaction and design possibilities in the future. The study also envisages that assessing living materials as material resources and crafting them will be standard practices in the future.**

However, with the evolving focus of biodesign, which includes livingness as a characteristic of material quality (Karana et al., 2020), the issue of sustainability in the making of living materials, in terms of integrating technologies and material fabrication, is yet to be well understood, considering the making practices explained above. In the introduction and literature review chapters, sustainability is featured as one of the most prominent drivers for designers to be interested in designing with new and living materials (Camere & Karana, 2018a; Karana et al., 2014; Rognoli et al., 2015). Also, biodesign is closely related to sustainability practices, especially when the production processes of an artefact (Camere & Karana, 2017) is considered. Nevertheless, **this research has shown that the making of living materials within the frame of achieving sustainability requires a novel elaboration of present theories towards the relationship between sustainability and living materials, especially for cohabitation possibilities.** The current approaches in DfS theory (Ceschin & Gaziulusoy, 2016) and sustainable design considerations (Doğan, 2012) remain insufficient to explain and understand the sustainable design motivations that drive biodesign practices. Since there are two different stakeholders in biodesign practices, humans and organisms, the current definitions stay *forced* rather than *inclusive* with their focus on *sustainability for humans*. As a result, while the approach to SDGs is obvious in terms of 'problem-solving,' it is difficult to recognise a high-quality argumentation in terms of DfS and the sustainability needs of the living materials/artefacts themselves. Because attention is traditionally paid to strategies to sustain human requirements, more effort on this topic will be required in the coming years.

7.3.2 Design Fiction for Biodesign

Another aspect of the main conclusions is the evaluation of the method developed and applied for this research, as presented in the analysis chapter. The findings in the analysis implicate conclusions not only in terms of 'evaluation of the application' per se but also the nature of biodesign. Therefore, besides what has been featured for further development of the method in the analysis chapter, main conclusions emerged considering the nature of biodesign and design fiction as an educational and generative tool.

Design Fiction to Reveal Biofutures

Using design fiction to research biological futures is becoming a popular method (Çağlar, 2021; Ertürkan et al., 2022; Gough et al., 2021; Hupkes & Hedman, 2022), but biodesign fiction applications are primarily based on individual efforts of designers and design researchers (Collet, 2013; Dunne & Raby, 2013; Myers, 2012, 2015). On the other hand, the fuzziness of biodesign, whether intentional or unintentional, allows a discussion-rich area such as design fiction to handle the topic. Also, the field of biodesign, which is still developing (and often technology integrated), creates an extra benefit for speculative areas such as design fiction with the aim of explorations.

Therefore, based on the empirical study and the prior research, it is concluded that design fiction is an efficient tool for researching biofutures and uncovering potentials for designing with living materials. Especially the debatable and ‘immature’ nature of biodesign and bio-applications in design makes speculative design methods such as design fiction a perfect match to investigate potentialities of the topic when ‘future of’ or ‘what if’ inquiries are involved.

In Need for Biodesign Education and Ideation

Biodesign is not an area in many design education curricula; it is a practice-led approach requiring certain facilities. Scholars mention the need for novel methods and tools to investigate biodesign (Karana et al., 2019). However, the biodesign practice needs specific physical requirements making the area harder to approach or more challenging to be positioned as a part of design education or the design profession, decreasing its accessibility. On the other hand, in the literature, the importance of an interdisciplinary framework for materials development (Barati & Karana, 2019) and biodesign (Camere & Karana, 2018) is highlighted. However, since interdisciplinary collaborations are not easy to be formed and maintained (Nancarrow, 2013), biodesign is staying within the actualisation barrier.

Therefore, considering the fuzziness of biodesign and the requirements to design with actual living materials, **the area calls for novel ideation tools and more ‘reachable’ applications such as those developed and utilized in this study.** Considering the sampling, which is formed of design graduates, the knowledge towards biodesign was slight. Therefore, **biodesign education to improve knowledge and interest could and should become a part of design education in raising new Biodesigners or material designers in general.**

7.4 Limitations of the Research

First, as it has been addressed numerous times and later became a motivation for the research design, the required facilities and tools for conducting hands-on, practice-driven living materials research could not be reached. Therefore, a sensitisation process in a field trip had to be carried out to explore further knowledge and see things without being wholly alienated from the practicality of the subject. Parallel to this issue, an attempt to recruit living materials from abroad had been considered. However, the legal regulations regarding the import of living materials obstructed the attempt, by not allowing the trading of such living organisms (namely, bioluminescent algae, *pyrocystis fusiformis,* https://pyrofarms.com/), which was initially intended to be investigated. However, later on, benefiting from the ambiguity of the area, the workshop was designed to allow people to think regardless of boundaries that practicalities inevitably bring.

Secondly, the workshop is conducted only once, considering the timeframe and recruitment process. With the aim of reaching out to design graduates (hence professionals), the workshop recruitment was especially challenging when the nature and duration of the research design (a creative process for actively working people takes a whole day) is considered. The reason for recruiting professionals is explained in Section 3.5.4. Conducting the workshop once may limit the generalisability of the results regarding the evaluation of the workshop. Also, being alone during the workshop process, and despite the presence of recording devices and assigning reporter roles which are also proven unusual, the data collection process – using the data collection sheets – did not go as planned. Adopting the role of both the researcher and researcher's assistant roles, I had to be involved in almost every issue involving contextual problems. This resulted in a lack of guidance for some participants during the generative session and later resulted in work overload during the analysis process.

Lastly, if not a direct limitation but initially considered a limitation, the sampling process was originally designed to recruit only industrial design graduates. However, when the required participant number could not be reached, the sampling process was extended to recruit architecture and interior architecture graduates, which resulted in richness in the data but also could be interpreted as the results being slightly affected (diverted away from product design). Acknowledging this, the architects who attended the workshop were grouped by the researcher, but the results showed that even more diverse disciplines could have been included, since the method proved to overcome the barriers caused by educational and professional backgrounds. On the other hand, no matter their background, the workshop's language and some terms made the workshop harder to process and fuzzier. Because of that, the workshop could have been more time-efficient and flowed more easily. Also, different results would have emerged if the contents had been created in Turkish but again, what could be considered a barrier caused more divergent outcomes during the workshop.

7.5 Suggestions for Further Studies

Directions for further studies can be drawn based on two main criteria. Whilst one of them could be interesting in discovering the future of living materials, the other would be based on the evolution of the workshop / data collection method by reapplying and developing it with updates based on the data that emerged from each application. Therefore, the potential for further studies could be very diverse since biodesign is still a developing area in many ways. Because of that, the suggestions for further studies could be outlined by taking a starting point from the main conclusions.

Linked to the main conclusions, first, investigating the human side of living material/artefact relationships in depth, including psychological and cognitive processes, can be a promising research and design area, especially when considering robust (durable and maintainable) relationships. Second, investigating the means of communication considering the two ends (maybe more) of these relationships can be useful. It can be beneficial to see if such an investigation yields novel potential in applying the biodesign in terms of practicality, language and meanings. Third, issues such as *utilisation, living ethics* and the *boundaries between livingness and materiality* of biodesign can be investigated in further studies, as they still keep their ambiguity in the field. On the other hand, such an investigation could be made on a specific type of organism to maintain *naturalness* during mutual cohabitation.

Parallelly, an in-depth exploration of the sustainability of living materials/artefacts and elaboration of DfS, particularly for living materials, is yet to be detailed.

Biodesign requires novel educational and ideation tools, especially when the ability to reach biodesign applications is limited. In this study, design fiction has proven to be an efficient method for investigating the 'future' of living materials in which we cohabitate. However, regardless of the notion of 'future,' biodesign can be investigated regarding pedagogy and design education for investigating the future and applications of living materials. Therefore, comprehensive research on designing novel curricula to educate future designers within the scope of biodesign can be a prominent suggestion for further studies. Moreover, the research on increasing collaborations around ideation tools in design education and the profession considering different stakeholders can also be a starting point for further studies.

A somewhat alternative, comparatively less common AI-supported tool could propose a novel research area. Within the scope of this research, Midjourney AI was used to express fictitious ideas visually, which were in a written format. In that sense, using AI-supported visualisation tools for design fiction research could yield potential for visualising Storyworlds. This case was valid in this research since the focused subject (biodesign futures) and the research method (design fiction) are aimed to '*open a discourse, ask questions and provoke discussions* (Dunne and Raby, 2013)' which are rather fuzzy and tend to be abstract. On the other hand, using such tools systematically for any other design research could be beneficial in other studies to express ideas; however, due to the novelty of both the tools and the idea of including them in design research, specific research that focuses on using and assessing them and could be a novel research area on its own.

7.5.1 Suggestions for Workshop Version II

Apart from broader suggestions which could be entirely new studies, the suggestions to further evaluate the workshop and conduct a second version are given below.

I. **Participant Selection:** The needed Storyworlds and material scenarios turned out not to require specialised material expertise; therefore, ID, Arch, and IArch students may not be the 'best' creatives for the design fiction workshop (at least with the current version of the workshop). Trying out alternative creative careers with more robust storytelling and narrative development skills could be beneficial (e.g., games design, cinema, graphic design, visual communication design). Additionally, the participants could be chosen based on their existing knowledge of science fiction, biology, and other non-professional interests.

II. **Elevating Material Discourse:** Compared to the material experiences and material attributes, the diegeses are more detailed in the overall Storyworld. It could have been brought on by a lack of understanding of the natural sciences (a solid background in relations between biology, physics, and sci-fi). Future workshops might be changed in terms of various aspects, such as a change in the emphasis, introducing a new set of cards that focus on materials, utilise hypothetical (or perhaps contradictory) material cards visualised by AI, such as fluffy wood, translucent metal, crumbly foam, etc. A revised workshop may contain multiple new 'material inputs.'

III. **Worksheets:** The worksheets used in the workshop were proven to be 'too constraining' for the participants since none of the groups used them efficiently and along with the intended aim (they were designed to guide the participants and provide them with a workspace). The information given on the worksheets is often overlooked; hence the participants required more direct inquiries from the researcher. As a better replacement, the worksheets would be designed to be more versatile, with space for participants to work freely. On the other hand, disregarding the idea of a single sheet and replacing it with multiple sheets based on the requirements of each step could be more helpful.

IV. **Cards:** It would be beneficial to include a one-sentence definition of the words and expressions on the cards because they contain some uncommon (not every day) English terms and idioms. Additionally, as the analysis showed, it can be advantageous to have all information available in English and Turkish to let participants switch between the two languages and overcome the language barrier. Additionally, the number of decks' intensity can be decreased (254 cards in nine decks).

V. **Usage of AI Visualisation Tool (Midjourney AI):** The narrative visuals from Midjourney could serve as a starting point rather than a conclusion. For instance, through follow-up interviews with groups to assist in honing and revising the narrative's details and features.

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APPENDICES

A. Informed Consent Form

INFORMED CONSENT FORM (WORKSHOP/GENERATIVE SESSION)

This study is conducted by Middle East Technical University, Department of Industrial Design Master's student Ali Cankat Alan for their M.Sc. thesis research. The thesis is supervised by Prof.Dr. Owain F. Pedgley. This form intends to inform you about this study and ask for your consent to be a participant.

Aim of the Study

The study aims to investigate the future of designing with living artefacts using design fiction methods by exploring the possible speculative experiential potentials, cohabitation possibilities, practices, and attitudes when we switch from inert products and infrastructure to biologically alive replacements.

Voluntary Participation

If you accept to participate in the study, you will be expected to participate in a workshop/generative session. The workshop will take between four to six hours, depending on the intensity of activities and the volume of outcomes at each step. Commitment for one full day will therefore be necessary. Participation in the study is voluntary, as you can withdraw at any time without giving a reason. Please do not hesitate to ask any questions at any time.

Information to be Collected

You will be expected to participate in a workshop/generative session organized in three main steps. Materials created during the session (e.g., sketch sheets, illustrations, sticky notes, digital files) will be kept by the researcher for analysis afterward. The session will be recorded in video and audio formats, capturing activities and conversations. Before recording starts and after recording ends, you will be notified.

Your Consent

The researcher and the researcher's supervisor will watch the session recordings and review the session outcomes to answer research questions and reach the aim of the study. No one else will watch the recordings or have access to the session outcomes. A thesis will be published containing your contributions, which may also be disseminated as a conference or journal article. All references to your contributions will be anonymous, meaning you will not be identifiable.

Thank you for your participation in this study. For further information, please contact:

Researcher: Ali Cankat Alan

Phone:

E-Mail:

I am participating in this study of my own will, and I am aware that I can withdraw my participation at any time. I consent to the use of the information I provide for scientific purposes, as explained above. (Please return this form to the researcher after you have filled it in and signed it).

Name – Surname Date
Signature

......../........../..........

B. Ethical Approval Letter

UYGULAMALI ETİK ARAŞTIRMA MERKEZİ
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13 EYLÜL 2022

Konu: Değerlendirme Sonucu

Gönderen: ODTÜ İnsan Araştırmaları Etik Kurulu (İAEK)

İlgi: İnsan Araştırmaları Etik Kurulu Başvurusu

Sayın Prof. Dr. Owain PEDGLEY

Danışmanlığını yürüttüğünüz Ali Cankat ALAN'ın **"Living with Living Materials: Experiential Speculations with Biologically Alive Products and Infrastructure"** başlıklı araştırması İnsan Araştırmaları Etik Kurulu tarafından uygun görülerek gerekli onay **0453-ODTUİAEK-2022** protokol numarası ile onaylanmıştır.

Bilgilerinize saygılarımla sunarım.

Figure B.1 Ethical Approval Letter

C. Data Collection Sheets

Table C.1 Example Tables from Data Collection Sheets, Page 1

PHASE 0: PRESENTATION AND DISCUSSION (30 min.)

Key points emerged during the presentation session.

Guide / Subject	Question/Comment/Discussion (Highlighted keyword, on which specific topic)	Slide	Further Details
Design Fiction	e.g., D. on the diegetic prototype.	12	The participants could not grasp it directly.
Biodesign			

Table C.2 Example Tables from Data Collection Sheets, Page 2

Biodesign Fiction			
Workshop Details			
Workshop Flow			

Table C.3 Example Tables from Data Collection Sheets, Page 3

PHASE 1: WORLD BUILDING

Key points emerged during the world-building session observed by a participant. It will be filled closer to the end of the phase.

Group Name Name of the World

Global Challenges/Opportunities		
		Further Details

Speculated Subject	Speculation (use a keyword if covers)	Usage of Card	Further Details
e.g., Religion	Robots/ robots formed a religion.	✓	
e.g., DIY Materials	A.I at home for the subject	✕	

The Pentagon	Economic	Political	Environmental	Societal	Technological

Table C.4 Example Tables from Data Collection Sheets, Page 4

PHASE 2: LIVING MATERIAL DESIGN

Key points emerged during the living material design session observed by visiting each group/ participant.

Group Name Name of The Living Material

Need	Behavior	Function	Other	The Keyword	Usage of Card	Further Details
✕				Sunlight	✓	The material needs sunlight because of photosynthesis.

Table C.5 Example Tables from Data Collection Sheets, Page 5

PHASE 3: DIEGETIC PROTOTYPING

The phase is divided into two separate phases.

PHASE 3A: USAGE APPLICATION SCENARIOS

Key points emerged during the usage application scenarios session observed by a participant.

Group Name Name of the Product

Design Potential with Explanation	Keywords and Usage of Card	Further Details
e.g., The material is embodied as a living sensor for detecting oxygen change in the environment	Living sensors ✓	

Table C.6 Example Tables from Data Collection Sheets, Page 6

PHASE 3B: ANTICIPATED UX

Key points emerged during the anticipated UX session observed by a participant. It is essential to differentiate the care action for the material.

Group Name   Name of the Product

Interaction Potential with Explanation	Keywords and Usage of Card	Is it a Care Action?	Further Details
e.g., The material needs sunlight, so the user should place it under the sunlight.	Sunlight ✓	✓	Since the product has been designed using a photosynthetic living material, it functions better with sunlight

Table C.7 Example Tables from Data Collection Sheets, Page 7

CHANGE SHEET

It is essential to note the changes regarding the precedent step if the change is decided in the following step. It can be an addition that should be clearly stated.

Group Name

In which step the change has occurred	Regarding which step	Why has the change occurred, or is it an addition	From (keyword) or addition	To (keyword)
e.g., Anticipated UX Phase	Material Design Phase	Because the material created did not fit the UX scenario later elaborated.	Photosynthesis	Digesting Plastics
e.g., Anticipated UX Phase	Material Design Phase	It is an additional keyword. Based on the scenario, the material also needed to have the feature of digesting plastics.	Digesting Plastics	

D. Workshop Poster

Figure D.1 Workshop Poster

E. Keywords Included in the Card Decks

Table E.1 Keywords Included in the Card Decks

The Keywords in the Global Challenges Card Deck		
World Hunger	Poverty and Economic Inequality	Gender Inequality
Pandemics	Water Pollution	Land Pollution
Invasion of Privacy	Goods Consumption and Production	Climate Change and Extreme Weathers
Fascism and Diversification	Biodiversity Decline	Aging Population
Over-population	Soil Degradation	Spread of Misinformation
Nuclear Threat	Healthcare Crisis	Forced Displacement
Job Loss and Unemployment	Miscarriage of Justice	Air Pollution
Deforestation	Microplastics	Fresh Water Scarcity
Corruption and Organized Crime	Energy Crisis	War and Terrorism
Increasing Natural Disasters	Dictatorship	Colonization
Food Consumption and Production		

Table E.1 Keywords Included in the Card Decks (continued)

The Keywords in the Global Opportunities Card Deck		
Novel Species	Genetic Modification	Renewable Energy
Space Travel	Colonies on Mars	Smart Cities
Diamond Batteries	Underground Cities	Underwater Cities
Machine Learning	Autonomous Mobility	Individualisation
Sharing Culture	Prosumerism	Glocalization
Blockchain	Decentralization	Flat Hierarchy
CRISPR	LGBTQ	Localism
Circular Economy	Vertical Habitats	Smart Products
Artificial Intelligence	Healthy Lifestyle	IoT
Personalized Health Systems	Empathy	Cloning
Sustainable Behaviour Change		

Table E.1 Keywords Included in the Card Decks (continued)

The Keywords in the Provocative Card Deck		
Imagine .... is automated now.	Imagine .... has become an ideology.	Imagine you can design your own ....
Imagine no .... left in the world.	Imagine you wear a	Imagine there is a .... problem.
Imagine a robot helps you to	Imagine you eat .... in your daily life.	Imagine .... has become more widespread.
Imagine you see .... in the streets.	Imagine people live together with a .... at home.	Imagine .... is over.
Imagine .... has become mainstream.	Imagine .... is banned.	Imagine there is a new energy source called ....
Imagine people spend most of their time	Imagine there is a ministry of	Imagine there is an institution called ....
Imagine people have become	Imagine .... is a very popular job.	Imagine there is a product for ....
Imagine there is a new law called	Imagine people have discovered	Imagine you miss ....
Imagine people believe in	Imagine there is a new religion called	Imagine .... is the new hype thing.
The Keywords in the Material Trends Card Deck		
3D Printing	Life Cycle Approach	Circularity
Biofabrication	Biodegradability	Edibility

Table E.1 Keywords Included in the Card Decks (continued)

Compostability	Genetic Modification	More Than Human Turn
Biomimicry	Biophilia	Custodian Role
Cloning	Smart Materials	Nanotechnology
Plant-based Nutrition	DIY Culture	Body Hacking
Microorganism-based Nutrition	Material Driven Design	Materials Experience
DIY Materials	Bio-based Materials	Digital Materials
Organic Waste Materials	Meta Materials	AR - VR
The Keywords in the Material Affordances Card Deck		
Affords Sticking	Affords Wrapping	Affords Shaping
Affords Holding	Affords Handling	Affords Pulling
Affords Pushing	Affords Tearing	Affords Smashing
Affords Wearing	Affords Touching	Affords Stabilizing

Table E.1 Keywords Included in the Card Decks (continued)

Affords Carrying	Affords Seeing Through	Affords Blocking
Affords Bending	Affords Knocking	Affords Folding
Affords Giving Sound	Affords Shining	Affords Rolling
Affords Throwing	Affords Burning	Affords Cooking
Affords Eating	Affords Writing On	Affords Lifting
Affords Cutting	Affords Closing	Affords Insulating
Affords Waterproofing	Affords Plugging	Affords Playing With
Affords Opening		
The Keywords in the Living Needs Card Deck		
Sterile Environment	Artificial Light	Moisture
Extremes	Motion	Dryness
Sunlight	Humidity	Minerals
Temperature	Darkness	Nutrients

Table E.1 Keywords Included in the Card Decks (continued)

Water	Air	
The Keywords in the Behaviour of the Living Card Deck		
Colour Changing	Light Giving	Doing Photosynthesis
Aerobic Respiration	Eating	Moving
Excreting	Growing	Reproducing
Reacting to Change	Communicating	Regenerating
Ageing	Decaying	Digesting
Anaerobic Respiration	Healing	Self-healing
Making Noise	Cleaning	Wetting
Surviving	Building Relationships	Smelling
Sensing	Hearing	Building
Producing	Touching	Flying
Fighting	Sticking	Consuming

Table E.1 Keywords Included in the Card Decks (continued)

Hiding	Camouflaging	
The Keywords in the Designing and Making with Living Card Deck		
Living Sensors	Living Textiles	Hybrid Materials
Embedding in Other Materials	Combining with Other Materials	Human-Computer Interaction
Encapsulation	Soft Interfaces	Open Interaction
Closed Interaction	Petri-Dish System	Biofabrication
Biohybridization	Incubation	Inoculation
Co-designing	Growing	Genetically Programming
Virtual Environment	Hard Interfaces	Living Interfaces
Providing Feedback	Integrating	Incorporating
Programming	Lighting	Air Purifying
Alarming	Showing	Carrying
Eating	Material Quality	3D Printing

Table E.1 Keywords Included in the Card Decks (continued)

Wearing	Composting	Personalizing
Differentiating	Crafting	Cultivating
The Keywords in the Caring for Living Card Deck		
Feeding	Culturing	Fermenting
Moving	Watering	Replacing
Cleaning	Tidying Up	Disposing
Re-energizing	Nurturing	Re-cultivating
Re-animating	Hard Interfaces	

F. Tips Brochure for Participants

TIPS

SHAPINGFUTURES

Welcome to the Shaping Futures™. It is a design fiction workshop by Ali Cankat Alan to create speculative future scenarios and diegetic prototypes. It is the living materials edition explicitly designed to speculate on biodesign futures.

Forming a group for the workshop is recommended since group work can positively affect your creative output and ease your work.

There will be a working sheet and card decks to enhance your creativity and ease your working flow. The necessary equipment will be provided by the facilitator(s) of the workshop. It is recommended to use digital creative tools during the workshop; however, it is not necessary as the workshop can be completed with just basic drawing equipment.

The card decks include keywords responding to the aim of the respective stage, and they do not include any visuals to refrain from affecting your creative process. Nevertheless, if drawing is not applicable, researching and finding your own visuals and the info for the keywords you are unfamiliar with are highly recommended.

The card decks given are not mandatory but encouraged. You can redraw, share, and, most importantly you could, add your own keywords during the process. After looking at the card, plase put the card back in the deck it belongs so that the others could draw!

Using a combination of text and visuals during the workshop is of utmost importance, as it can influence your input for the next phase and the final output.

Specific requirements and directions for each step will be announced and shown by the facilitator. You can go back and reshape the previous stage at any time.

The workshop consists of three stages, and the details of each step will be explained at the beginning of the workshop.

Despite the tips above, do not forget that it is a creative workshop, so freedom in any way is highly welcomed.

FLOW

SHAPINGFUTURES

Presentation and Briefing Session (30min)
A presentation on workshop flow and prominent theories featured in the workshop. Please participate in the presentation as it has been designed as a conversation.

Phase I: World Building
Participants are expected to design a world in which they further speculate starting by taking two cards each from **"global challanges deck"** and **"global opportunities deck"** and placing them.

1. Express the world as descriptive as possible by filling in the pentagon and defining other details (e.g., a person, a place, an institution, etc.).
Participants should take cards from the **"provocative deck."**

2. Imagine the future of materials and production practices in the world participants have created.
Participants should take cards from the **"material trends deck."**

Phase II: Living Material Design
Participants are expected to design living material(s) considering its needs and behaviours and have to start by defining two affordances by taking two cards from **"material affordances deck."**

Participants should take cards from the **"living needs deck"** and the **"behavior of living deck."**

Phase III: Diegetic Prototyping
Participants are expected to embody the created material on a product in a context that emerges from the world-building activity by considering conceptualizing living artifact topics.

1. Explore and propose usage scenarios and products/infrastructures that utilize the affordances of their material.
Participants should take cards from the **"designing and making with living deck."**

2. Empathize as owners, users, or custodians of the living products/infrastructure proposed in the previous activity.
Participants should take cards from the **"caring for living deck."**

Figure F.1 Tips Brochure for Participants

G. Briefing Presentation

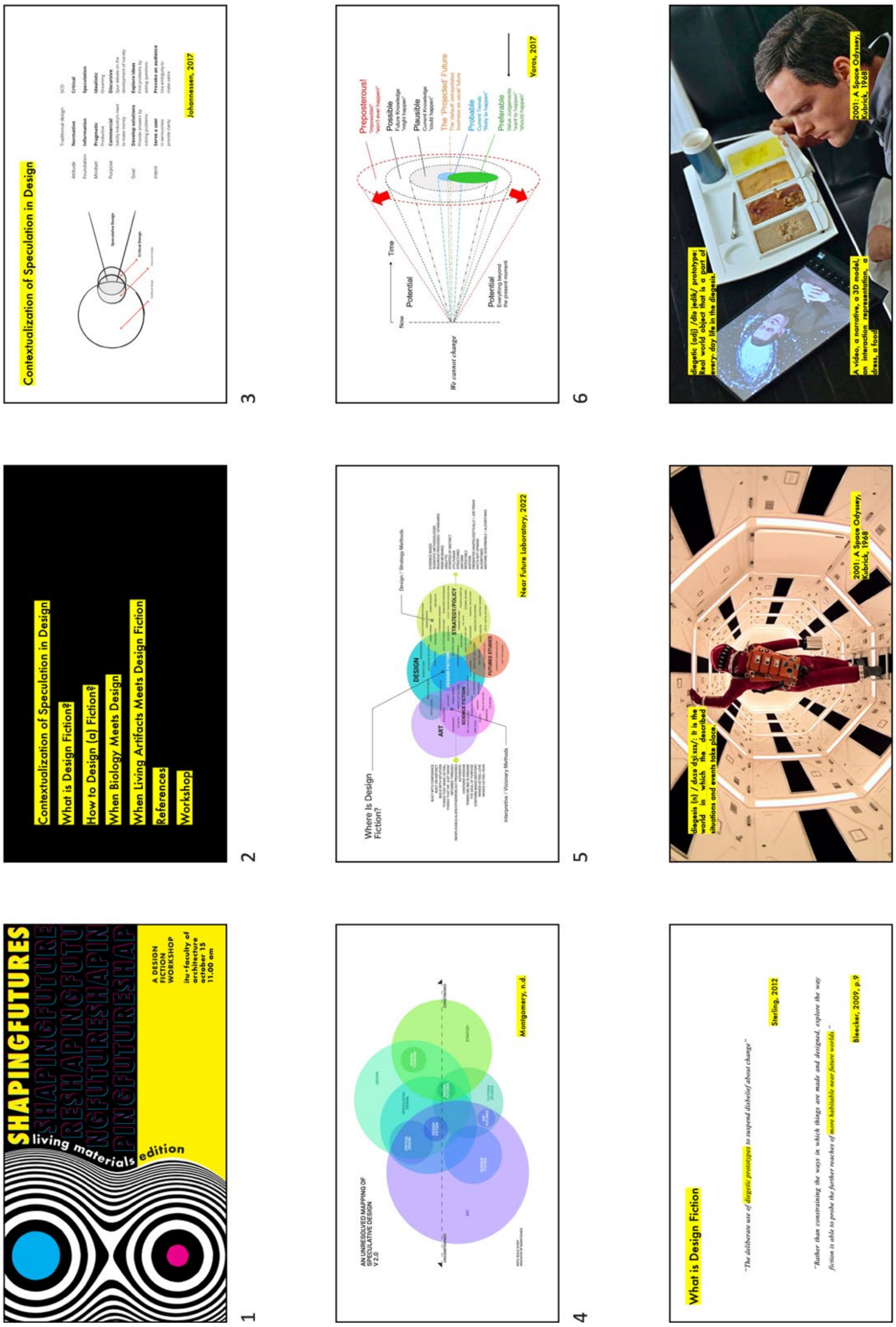


Figure G.1 First Set of Presentation Pages

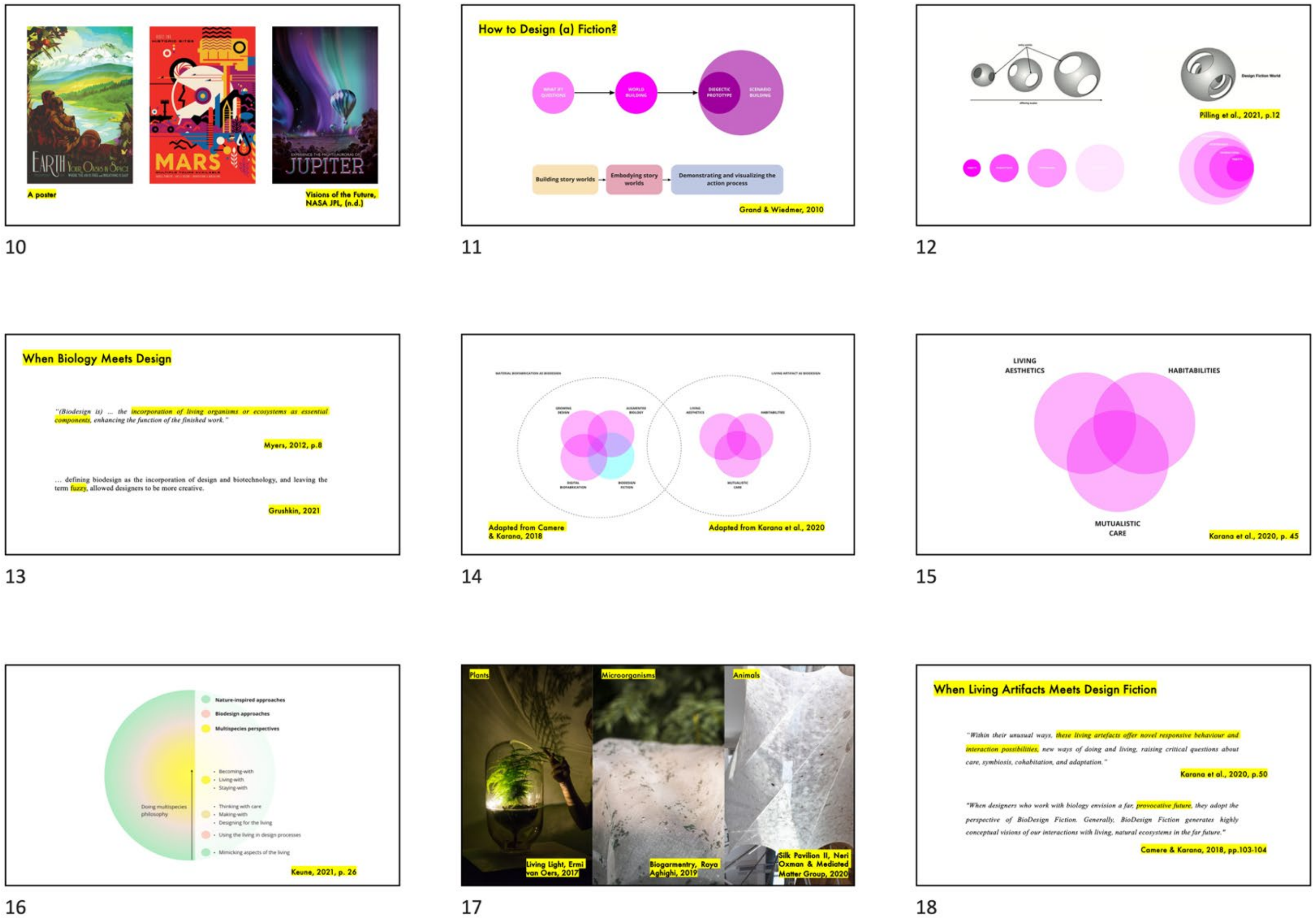


Figure G.2 Second Set of Presentation Pages

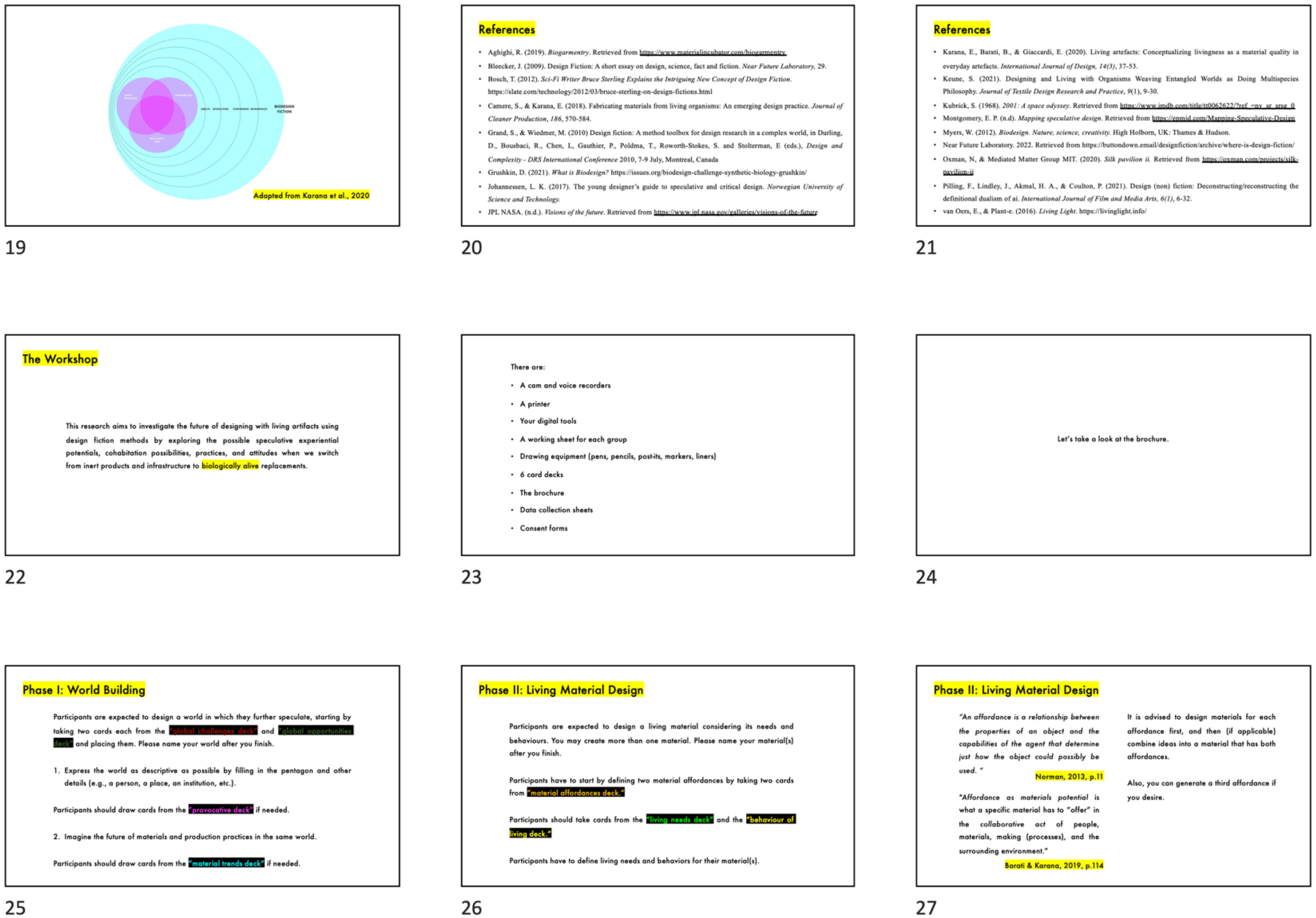
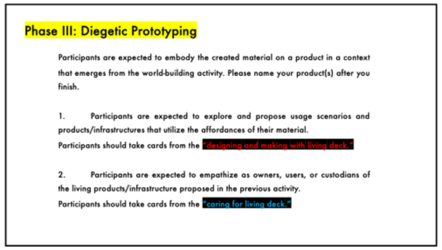


Figure G.3 Third Set of Presentation Pages



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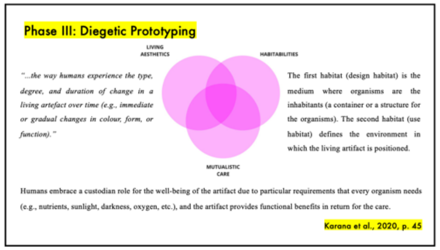

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Figure G.4 Fourth Set of Presentation Pages

H. Narrative Creation Process

Figure H.1 Narrative Creation Process