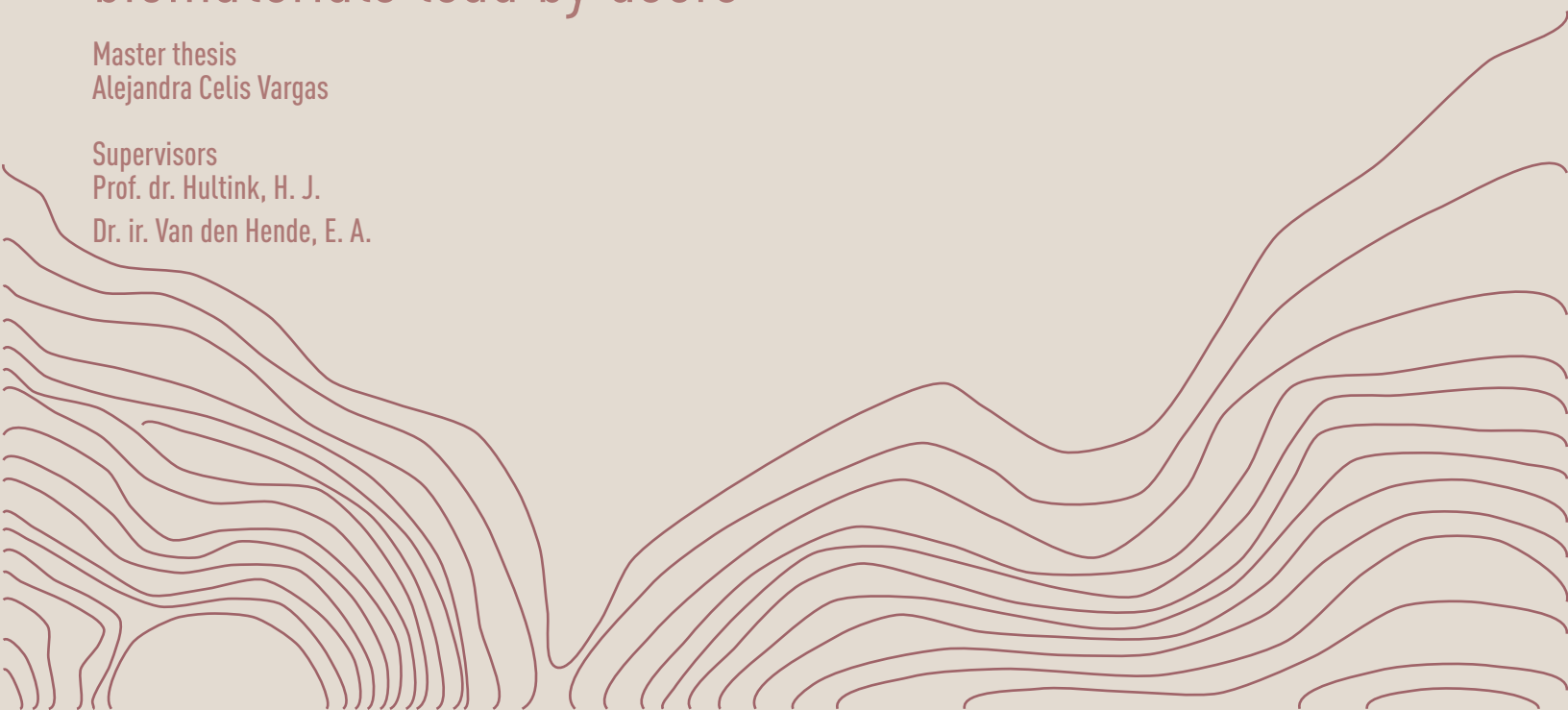
THE FUTURE IS BIO-BASED:

Towards a sustainability transition of biomaterials lead by users

Master thesis
Alejandra Celis Vargas

Supervisors
Prof. dr. Hultink, H. J.
Dr. ir. Van den Hende, E. A.



GRADUATION PROJECT

The future is bio-based: Towards a sustainability transition of biomaterials lead by users

Master thesis Strategic product design
Alejandra Celis Vargas
Student number 4911830

Supervisors
Prof. dr. Hultink, H. J.
Dr. ir. Van den Hende, E. A.

Faculty of Industrial Design Engineering
Delft University of Technology

January 2021

EXECUTIVE SUMMARY

ABSTRACT

A bio-based future where biomaterials are part of everyday life is the vision and entry point of this thesis. Achieving this scenario requires changes in socio-technical systems by cutting non-renewable materials and redefining cultural and behavioural dynamics in the production-consumption value chain.
With a focus on user experience, this research proposes the following. How can the user experience with materials be used as a driver in the biomaterial transition?
Several theories related to materials, diffusion of innovations, and sustainability transitions address the challenges and potentials of the biomaterial transition separately. However, there is not an integrated approach. This research aims to tackle this gap articulating a literature review and three exploratory studies as research stages. The results broaden the perception of biomaterials as disruptive innovations. Thus, deepening in their role in shaping social practices redefine the material culture towards a sustainability transition.

CONCEPTUAL FRAMEWORK

The project articulates theories about the material experience (Giaccardi & Karana, 2015) and sustainable practices in a niche level (Rauschmayer et al. 2015) to bridge technology and market in adoption cycles.

Literature on materials looks at new materials as radical innovations (Karana et al. 2018), and stands their role in shaping social and cultural practices. Diffusion of innovation addresses adoption processes considering the innovativeness of users and attributes of the invention (material meanings). However, for both theories, the lack of sustainability perspective and methods for deliberately influence socio-technical change weaks their influence towards a transition. On the other side, transition theory provides a wider perspective of a system in a Multi-Level perspective (MLP). In addition, it allows to identify lock-in patterns and destabilising patterns of change in an actual regime towards a new sustainable one.

EMPIRICAL STUDY (STAGES 1-2-3)

The empirical study was carried out in three stages to gain practical knowledge about the biomaterial transition in user's dynamics. Each was settled focusing individually on one of the three goals of the transition theory: description, interpretation and support to the transition.

Overall, Stage 1 focused on identifying user & biomaterial dynamics describing look-in patterns and patterns of change in the actual regime through an online review of user comments about available bio-based products. To undercover motivations behind the disruptive innovations on the niche level, stage 2 outlined the user journey with biomaterials based on users' dimensions and narratives during generative sessions. Finally, Stage 3 focused on how to empower the biomaterial niches lead by users gaining insights from different actors in the regime and land-scape levels, through interviews.

RESULTS

Material experience for sustainable social practices is a user-centred approach that frames patterns of change in the relation users, skills towards sustainability, material and meaning. This material experience for sustainable practices develops in relation of a social journey of adoption and diffusion of biomaterials as radical innovations. This connection allows to scale-up initiatives able to break lock-in patters of the current regime in material development, product design and policy.

CONCLUSION

The research proposes a bottom-up approach where niches are transition arenas for radical innovations that must be connected and empowered to scale them up as disruptive innovations creating a new regime.

The user experience with materials is a driver in the biomaterial transition creating a frame of user-centred approach by settling transition arenas where people (more than users) can find and co-create material meanings and new social practices in their experience with bio-based products. Transition arenas with a focus on users can develop open biomaterial processes and train sustainable skills. This user-centred approach occurs in diffusion/ adoption cycles based on social influence where people generate content to teach and spread the new material meaning and developed skills.

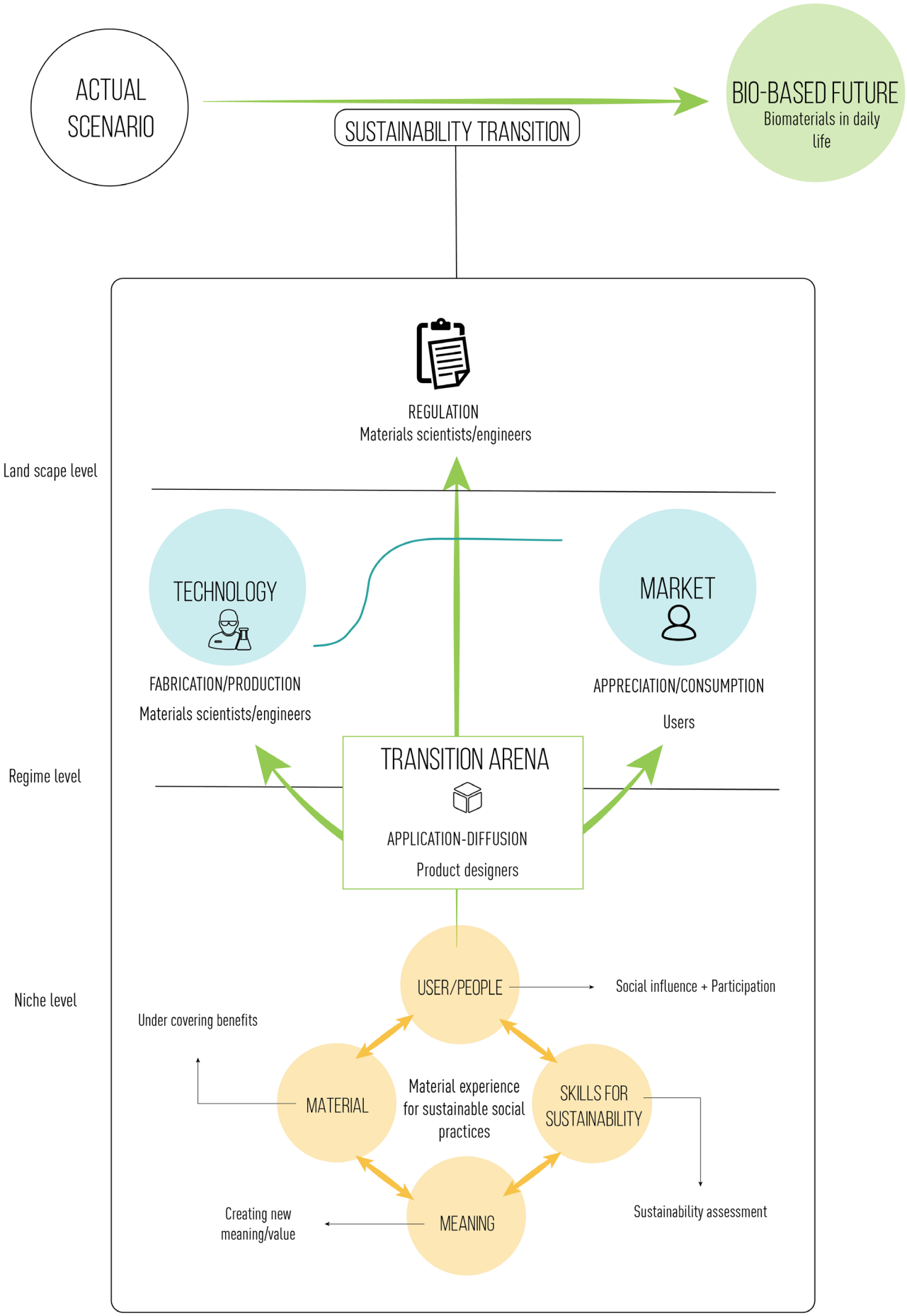

ACTUAL SCENARIO
SUSTAINABILITY TRANSITION
BIO-BASED FUTURE
Biomaterials in daily life
REGULATION
Materials scientists/engineers
Land scape level
TECHNOLOGY
MARKET
FABRICATION/PRODUCTION
Materials scientists/engineers
APPRECIATION/CONSUMPTION
Users
Regime level
TRANSITION ARENA
APPLICATION-DIFFUSION
Product designers
Niche level
USER/PEOPLE
Social influence + Participation
Under covering benefits
MATERIAL
Material experience for sustainable social practices
SKILLS FOR SUSTAINABILITY
Creating new meaning/value
MEANING
Sustainability assessment

TABLE OF

CONTENT

INTRODUCTION

One day, you, me, and some more appeared in a weird world, bright and dark at the same time, a place full of confusion and contradiction. It was easy for us to be indifferent but it was more exciting to widely open our senses and minds to understand that it is a board and we are pieces playing a long game. In this game, we permanently transition from one state to the other. The present is a transition arena where we can play with experiences and discoveries from the past and set a vision for our desirable future. As we are transitioning, the built environment that surrounds us has to transit too.

A desirable future is a sustainable one. An extended field about sustainability transitions from the 90's supports this statement. Approaches such as sustainable development, circular economy, and bio-economy[1] highlight the importance of cutting non-renewable materials, and the need of cultural and behavioural changes in the production-consumption value chain (Appels et al, 2019; Urmetzer et al, 2020). However, the biggest challenges to achieve a sustainable future remain unsolved (Loorbach et al. 2020; Urmetzer et al, 2020; Köhler et al. 2019; STRN, 2017). According to Cramer (2020), the slow implementation of sustainable approaches in the EU is primarily due to cultural barriers such as limited consumer interest and a reluctant business culture rather than technological barriers.

People, companies, and governments seek a more sustainable future, however, in practice it is a complex goal to achieve due to citizens' short-term focus and firms' need to secure short-term survival (Farla et al. 2012). Consumers are more aware of sustainable products, however, there are several limitations and inconsistencies about their behaviour explained by linking their motivations and opportunities to act sustainably (Verplanken, 2018). On the other hand, material development processes like other innovation processes, are risky due to the large demand for resources and the uncertainty of their success afterward in the market. In fact, the majority of new products in the market fail to diffuse (Danneels & Kleinschmidt, 2001). It is confusing for the different actors involved in the production-consumption chain what are the best decisions to move forward to the most desirable future. Changes in the actual system implies re-framing the roles and dynamics between different actors (academics, industry, government, and civil society).

A bio-based future where biomaterials are part of everyday life is the vision and entry point of this thesis. Several theories related to materials, diffusion of innovations, and transition address the challenge and potential of this shift separately, however, there is still no integrated approach. The research project presented in the following aims to fill this gap.

A transition having a core meaning of 'going across' addresses the process of a radical, non-linear and structural change in socio-technical systems (Farla et al., 2012, Köhler et al., 2019 and Hölscher et al., 2018). Furthermore, sustainability transition theory elaborates on how to describe, interpret, and support transitions by connecting several disruptive changes in multi-level perspective (Rauschmayer et al. 2015). Innovation theory analyses the relevance and process

1 Bio-economy: an economy based on innovative methods to substitute fossil resources with the intelligent and efficient use of bio-based materials and processes. Urmetzer et al. (2020)

of spreading an innovation (radical change) in the market following adoption cycles. On the other side, Giaccardi & Karana (2015) state how the perception of materials is more than physical and transcends to personal and social life, so materials and social practices are closely related.

This project proposes a change in the point of view of users and materials by addressing the question: How can the user experience with materials be used as a driver in the biomaterial transition?. This is a strategic approach to a topic that has been addressed from a technical and top-down perspective. For instance, the research seeks for broadening the perception of materials from their development and properties to deepening in their role as part of the material culture, shaping social practices to redefine the materiality towards the sustainability transition. This project articulates a literature review and three exploratory studies as research stages in order to answer the research question.

The literature review builds a conceptual framework about materials, diffusion of innovation, and transition theory. The empirical stages seek for gaining practical knowledge about users and biomaterials in the production-consumption chain. An online review of dynamics in the actual regime, generative sessions with users and validation interviews with other actors were conducted. The results merge a theoretical and practical approach. Firstly a conceptual and a practical framework for the biomaterial transition, secondly a map of user & biomaterial dynamics in the actual regime, a user journey with biomaterials, and a user-centred future vision, merged in a concept tool.

PRACTICAL REMARKS FOR THE READER

The project articulates a literature review and 3 empirical studies or research stages, each one developed to gain practical knowledge about the topic based on the theory.

Mixed methods were used to collect and analyse qualitative data. Considering the grounded theory method (GTM) an inductive process to analyse the data from observations until a theory was conducted. Additionally, the literature review was key to analyse the data before and after each stage and develop the different outcomes.

This document has 8 chapters that will guide you through the graduation project and research about the biomaterial transition. Chapter 1 introduces the project, roots, and overall methodology. Chapter 2 presents the literature review about the three main topics supporting the research question, to merge them into a conceptual framework. Chapters 3 to 5 address the stages of the empirical study individually. Chapter 6 concludes by integrating the findings of the stages with the theory. Finally, a discussion section is presented.

Even though this document is built in linear manner, the process was rather iterative, from the literature going through the 3 stages, each building on the previous outcomes and coming back to the literature to analyse the data.

Enjoy it.

CHAPTER 1

The resear

This chapter presents the structure and framework of the project, starting from the problem definition, until introducing the methods and development. Additionally, this chapter will outline the research approach.

The development was an iterative process, rich in qualitative data about the biomaterial transition, and also challenging by addressing different theoretical perspectives. Additionally, this project looks for building on the knowledge about material and sustainability transition from a strategic design perspective that in practice invites to reconsider how materials are developed and the role of different actors to bridge technology and markets.

The approach to the project is the research through design (RtD). The outcomes can lead to further research as it will be discussed in the last chapters.

rch project

PROBLEM DEFINITION

According to Hölscher et al., (2018) transition has become a buzzword in political and scientific discourses which signals the need for large-scale changes to achieve a sustainable society. Furthermore, Loorbach et al. (2020) elaborate on how governance of sustainability transitions have entered mainstream discourses because sustainability problems continue increasing (climate change, loss of biodiversity, resource depletion, and inequality) as well as the inability to change direction to address them successfully. Sustainable transitions are described as complex and long-term processes framed in multi-level and multi-actor perspectives enabling innovation, learning, collaboration, and knowledge integration (Farla et al., 2012). However, Farla et al. (2012) highlight that even when these transitions unfold over decades, the nature of sustainability problems requires imminent action.

Global economies continue to develop along unsustainable pathways and the way we consume and what we consume in our daily life mainly continue to depend on fossil sources (plastic). Farla et al., (2012) elaborate on reasons such as the tension of citizens' short-term focus and firms' need to secure short-term survival which makes it difficult for policymakers to implement ambitious sustainability programs. Cramer (2020) states that individual economic actors, particularly those connected to established technologies, are often hesitant to take the lead in disruptive change which might conflict with their current business, newcomers in the market are more inclined to adopt alternatives but are usually confronted with the problem of getting their product or service accepted. Moreover, Loorbach et al. (2020) argue that a key problem is a policy-driven innovation that presumes rational, planned innovation journeys of technologies that a certain point will scale and diffuse through market mechanisms, and often ignores other types of less technology-driven innovations that emerge organically within society such as novel lifestyles, business models or organisational forms.

Several authors (Farla et al., 2012, Rotmans et al., 2001; Rauschmayer et al. 2015; Loorbach et al., 2017; Vargo et al. 2020) agree on the importance of a more bottom-up approach to address changes in practice from a consumer and market perspective.

Hereby, the biomaterials transition contributes to shift the production-consumption chain to renewable resources but also helps to shape the transition itself, considering the active role of materials in shaping social and cultural practices. (Camere & Karana, 2018). However, the introduction of new materials in the market needs to be reconsidered, it is ironic that plastic, a material whose longevity is phenomenal, is used to produce disposable products (Karana et al., 2014).

According to sustainability transition theory there are two kinds of patterns that can whether enable or not a transition, lock-in patterns, keeping system dynamics in the actual regime in a loop or equilibrium of apparent changes that lead to the same negative outcome, and patterns of change that highlight disruptive innovations in the niche/individual level that can break the actual dynamics and support a new regime. Biomaterials are at an individual/niche level without scaling up to stable dynamics in a regime level. However, counteracting some of the lock-in patterns by a new bottom-up perspective from the material experience and users skills building toward sustainability can support and potentialise those niche initiatives as radical disruptions in a sustainable transition. Currently, it is possible to see disruptive initiatives in several levels such as new approaches to material development, several options of biomaterials in the market, and the increasing awareness about sustainability that reflects an increasing need for materials development. Additionally, materials increasingly gain users' recognition as criteria for purchase decisions and sustainable consumer practices are more frequently adopted.

There is a latent potential to innovate and advance the field of material development and design. However there is a gap in the literature about material transition related to material culture and consumer behaviour in sustainable transitions.

RESEARCH QUESTION

The research seeks for answering the question: ***How can the user experience with materials be used as a driver in the biomaterial transition?*** Considering materials as means and users as initiators of innovation pushing the diffusion and adoption in markets and society. Figure 1 briefly visualise this idea behind.

Figure 1. Users pushing a material transition towards a sustainability transition

The research question is framed in the proposition of a transition from the actual regime to bio-based future where biomaterials are widely adopted and implemented in the production-consumption value chain. Figure 2 visualises the scope of the project, and highlights the gap between technology and market to shape, and the opportunity of using this gap as transition arenas.

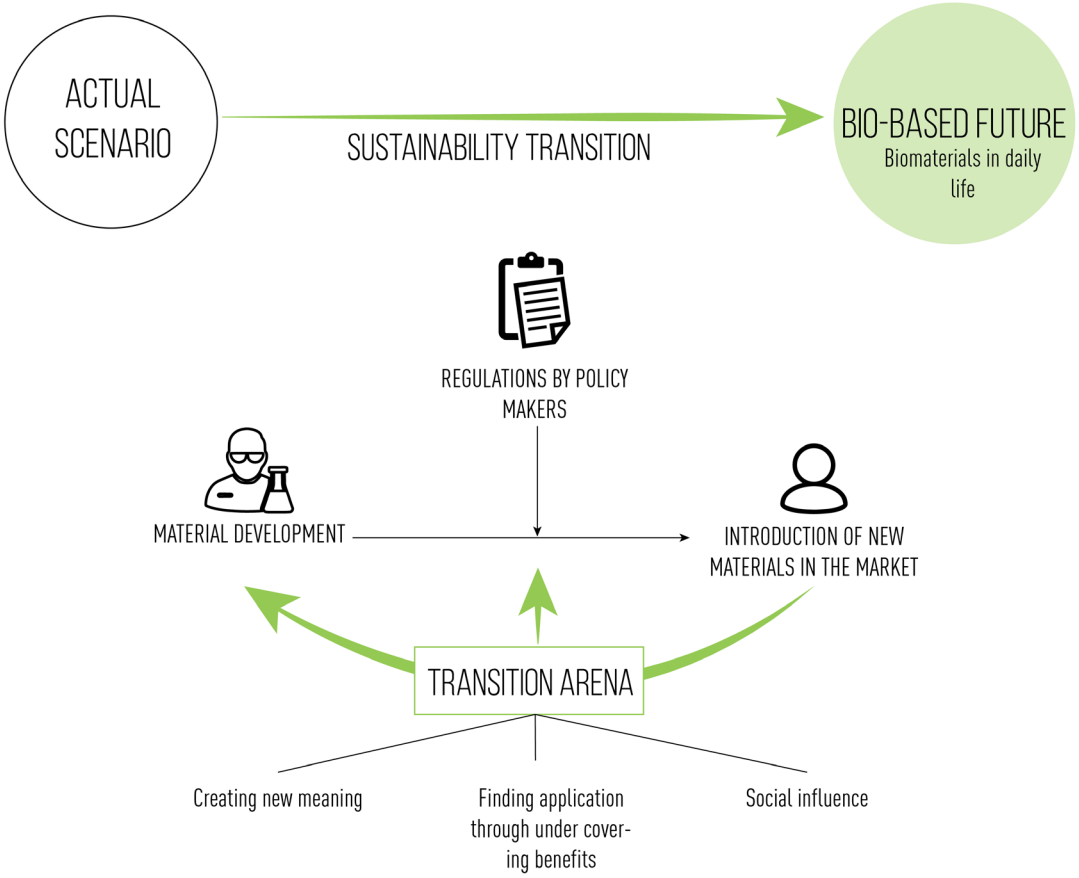


Figure 2. Project framework

RELEVANCE OF THE PROJECT

The relevance of the project is related to the need for more practical views to sustainable problems, that is closely related to the need of change in the production-consumption change to re-invent materiality around and unsustainable behaviours. As presented by Loorbach et al. (2020) we are living a time of mainstream calls for systemic change to achieve sustainable futures. The United Nations Convention on Biodiversity, the European Environmental Agency, the OECD, the German Advisory Council on Global Change, the European Union and national governments declare the importance of taking actions within ecological boundaries before 2050. Additionally, a transition of materials is urgently needed because of the shortage of raw materials worldwide and specially, Europe's strong dependency on their import (90% import from non-European Union countries) (Cramer, 2017).

On the other hand, the design field is currently addressing two perspectives about transitions, the emerging transition design (Gaziulusoy and Erdoğan Öztekin, 2019) and a design in transition ("Out Of Tune, living with invisibles," 2019). The first one, transition design is about the role of design in the current complex challenges or design for sustainability transitions (DfST) that resides at the socio-technical innovation level and incorporates spatio-social, product-service system, product, and material innovations. The second one, design is transition is about the practice of design by merging business, humans, and technology. The current project pursue to build in both by scoping the user interaction with materiality as a latent potential to achieve a more sustainable future to accelerate the current transition.

Research through design

Literature presents three approaches of design research: research about design, research for design and research through design. Zimmerman et. al. (2010) present research through design (RtD) as an emerging approach that employs methods with a focus on the future and adopts processes from design practice as a legitimate method of inquiry, and analysing data. The outcome of the RtD aims for identifying gaps in actual theories, proposes new materials or technologies, and stands a preferred state for the phenomenon by iteratively develop conceptual frameworks, guiding philosophies or artefacts. Additionally, Zimmerman et al (2010) link the RtD with the concept of "Wicked Problems" (Kolko, 2012) which needs a different approach due to those seek for a solution rather than for proving a hypothesis.

The material transition as a sustainability transition can be seen as a wicked problem. The current research project adopts the RtD approach considering the complexity of sustainability transitions, and the focus on material and user dynamics. Therefore, convergent and divergent moments were planned as stages involving different sources and actors, additionally, methods proper of the design practice were considered for data collection and analysing such as booklets and role games as tools for inquiring used in stage 2, and maps and journeys for data analysis. RtD was fundamental not just for gathering information but for enriching the collection of the data and the whole process.

PROJECT DEVELOPMENT

This project articulates a literature review and 3 exploratory studies (3 research stages). On one side, the literature review builds a conceptual framework about materials, diffusion of innovation, and transition theory. On the other side, the stages gain practical knowledge about the biomaterial transition in user's dynamics.
Figure 3 shows the iterative process between the literature review, three stages, and outcomes.

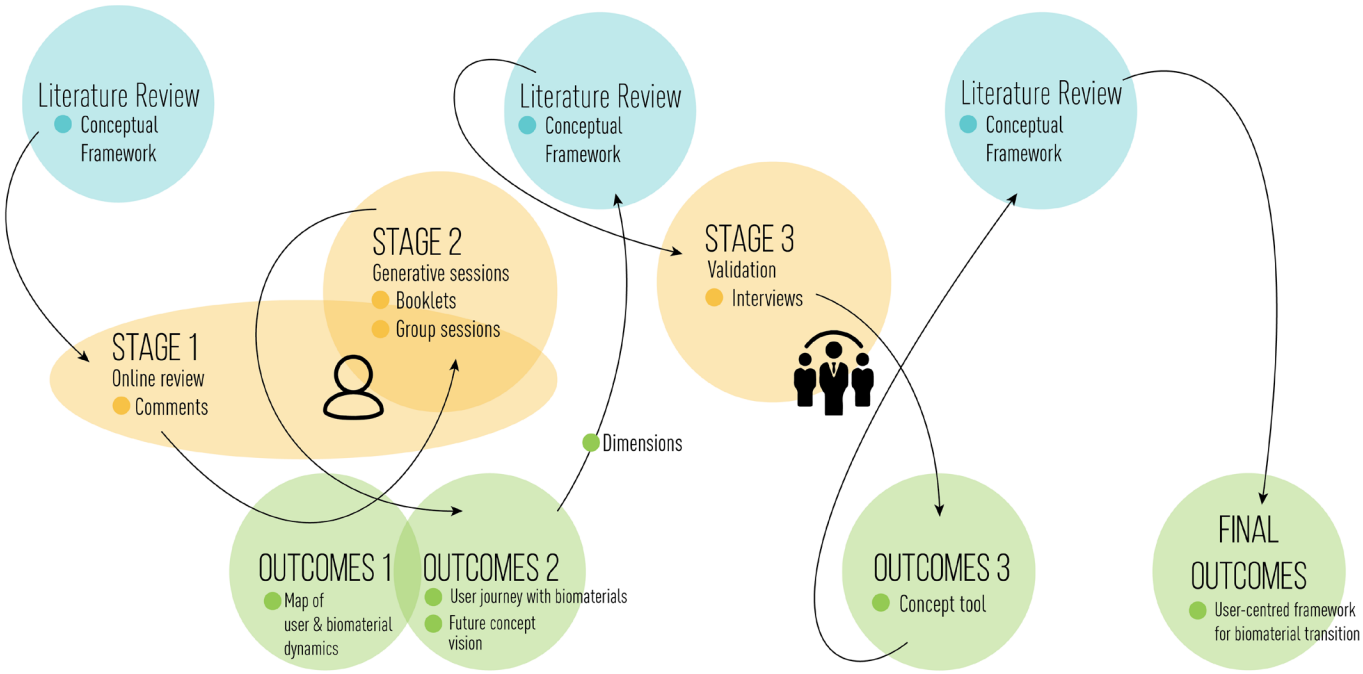


Figure 3. Project development

Overall, ***Stage 1- online review*** gained insides to map the actual scenario, ***Stage 2 – generative sessions*** explored the dimensions and narratives created by users through booklets and role game, and ***Stage 3 – open conversations*** gained insides from different actors discussing around the idea of a possible tools for accelerating the biomaterial transition.
The outcomes of the project are the result of an iterative process through the three stages where the outcome of one stage was input for the following one.

TAKE AWAY

The project pursues to give a practical look at the biomaterial transition, and the role of users interacting with biomaterials to speed up the whole sustainability transition by developing research through design RtD. For instance, literature review and exploratory studies were conducted.

New biomaterials are addressed as innovations, their transition is framed by sustainability transition theory, diffusion of innovations, and material experience theory to understand how the transition can be accelerated in practice. This framework builds a theory around the importance of social practices in the everyday life, where users are the ones finding meaning and re-defining dynamics in the regime.

This thesis builds in the sustainability transition field with a scope in materials and social practices. The research contributes to reconsider the actors involved and dynamics related to materials from development to use.

CHAPTER 2

Literatur

This section will outline the main literature currently available related to the research question. Three main topics act as theoretical knowledge base for the research: transition theory, diffusion of innovations, and materials. These are interrelated and complement each other.

The available literature about each topic is extended and has evolved over several years, however, there is a gap in merging the topics. This chapter will focus firstly on presenting each topic separately according to the relevant aspects for the research question, and secondly, on developing a conceptual framework to understand their relations and support the following chapters.

Analysing and merging the theories is an opportunity for answering the research question, it enables discovering the potential of material experience in shaping meaning and building skills towards sustainable practices. This potential can be used to support disruptive innovations as new dynamics in a future new regime where biomaterials are widely spread putting an end to our dependence on plastic.

e review

TRANSITION THEORY

Transition is in essence a process of change. Transition theory provides perspectives on how to describe, interpret, and support desirable radical and non-linear change in a socio-technical system defined in technological, organizational, and institutional terms for both production and consumption (Farla et al., 2012, Köhler et al., 2019, Hölscher et al., 2018, and Sengers et al. 2019), such as the shift from fossil-based materials to bio-based materials. The transition implies a shift from an actual regime or dynamic equilibrium to a more desirable one. Therefore, the central aim of transitions research is to conceptualize and explain how radical changes can occur.

Literature presents as main approaches to transitions the Transition Management TM and the Multi-Level perspective MLP. Rauschmayer et al. (2015) describe the MLP as three levels to analyse change: the niche, the regime, and the land-scape. Figure 4 presents a scheme of these three levels as presented by Vargo et al. 2020.

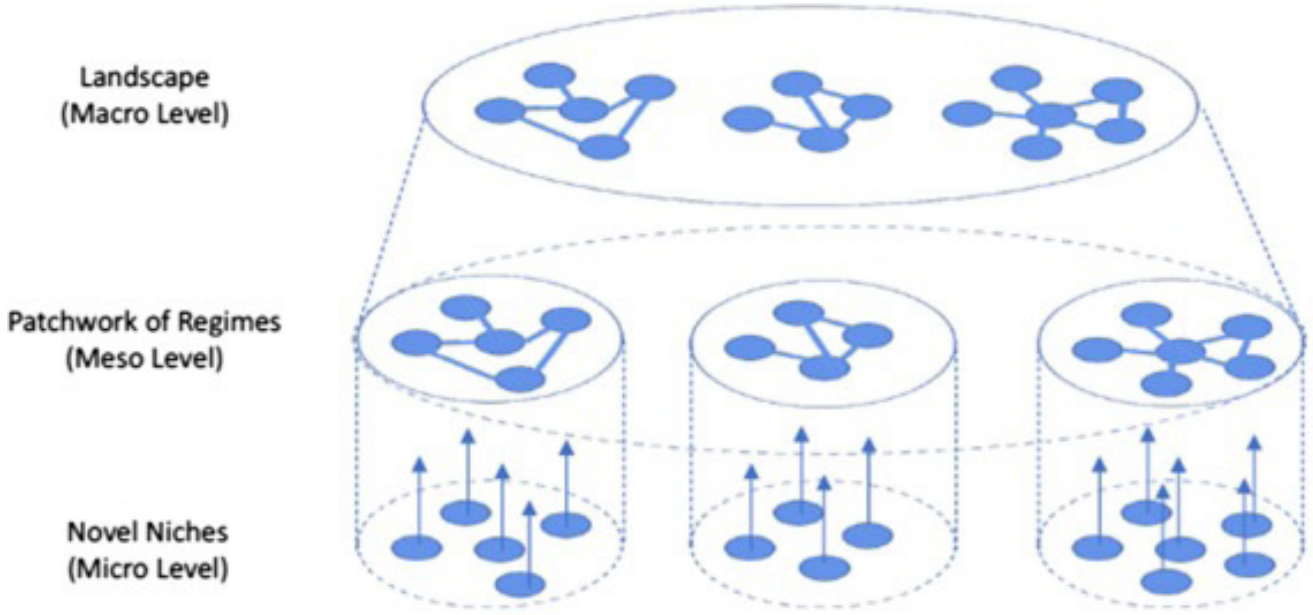


Figure 4. Multi-level perspective graph. Source: Vargo et al. 2020

Sustainability transition theory focus on the meso-level, the regime, defined as the way things are done in the 'normal', for instance, the regime is a main part of transition research, nevertheless, the three levels are closely related and mutually affected. (Farla et al., 2012; Köhler et al. 2019; Hölscher et al. 2018; Sengers et al. 2019).

The niche is related to the practice (rules, routines, and habits) and serves as an incubator room for radical innovations and experimentation. The landscape are cultural and normative values (prevailing perspectives), and material aspects such as infrastructure. Finally, the regime is an existing set of dynamics between different actors (civil society, companies and government) in all levels of a socio-technical system (Farla et al., 2012, Rotmans et al., 2001; Rauschmayer et al. 2015; Loorbach et al., 2017; Vargo et al. 2020). Moreover, existing regimes are characterized by lock-in and path dependence, and oriented towards incremental innovation along predictable trajectories, as described by Rauschmayer et al. (2015). Therefore, transition research seeks for finding ways to broke these patterns to transit to a new regime.

Rauschmayer et al. (2015) stand that shifts in regimes might happen via three, often interlinked basic dynamics: a) top-down, when landscape developments put pressure on the regime; b) bottom-up, when niches scale up and replicate or translate more widely their novel socio-technical arrangement and gain influence; and, c) when processes at the regime level lead to an integration of innovations from the niche level into the regime.

Additionally, Cramer (2020) present the complexity of these dynamics in practice, due to multiple conditions and drivers that can enhance or slow down the process of change. A frequent dynamic approach is described by Loorbach et al., (2020) when changes in land-scape level pressure the current regime, destabilizing configurations and actor activities, which creates new opportunities for innovations within the niche level to create an internal momentum to break the lock-in and configuring a new stable form of regime. In this top-down dynamic, governments are considered to be key actors (Rotmans et al., 2001) by formulating policies, facilitating innovation processes and creating suitable conditions. However, as stand by Cramer (2020), in reality, it strongly depends on the willingness of the market to innovate.

This critic of the top-down dynamic is supported by several authors as a gap of the sustainable transition theory in practice. More and more, recent literature seeks a major focus on the role of social practices in transition studies which implies a focus on the niche level (Upham et al. 2020). However, approaches such

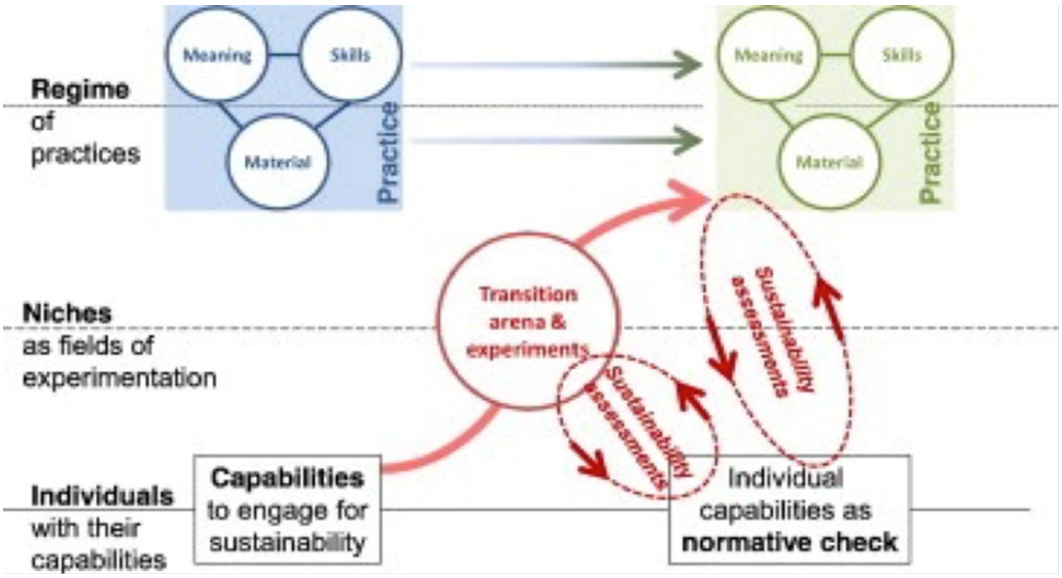


Figure 5. Transition management and capability approach for governing sustainability transitions. Source Rauschmayer et al. (2015)

as TM and MLP lack of this perspective, as supported by Rauschmayer et al. (2015), who complement the traditional MLP with a capabilities approach related to the skills of the individuals to opt for sustainable innovations and practice theory that relate the material experience and meaning attribution and the skills. Figure 5 presents this approach and focuses the attention on niches as transition arenas, where radical innovations can occur and scale-up to create new dynamics at the regime level.

In this perspective, a central aim of transition governance should be to empower niche actors to generate viable alternatives by developing missing capabilities. In other words, to influence and empower civil society in such a way that people themselves shape sustainability in their environments, and contribute to the desired transitions to sustainability (Rauschmayer et al. 2015).

MATERIALS

A material is a mediator in the production-consumption chain. Usually, the material development occurs based on technological capabilities to later on finding applications and consequently communicate these properties and applications to consumers. According to Barati & Karana (2019) materials are framed in three moments: fabrication, application and appreciation.

Fabrication is traditionally done by material scientists and engineers, the outcomes are lists of properties registered in material libraries as tables and samples, those are material potentials (form, functions and experience). When finding an application, usually designers in material selection processes embody the material in a product. Finally, appreciation refers to the introduction of the material in the market to find meanings by users. Figure 6 summarises how this process is traditionally done from the technology side to the market, and the actors involved in each moment.

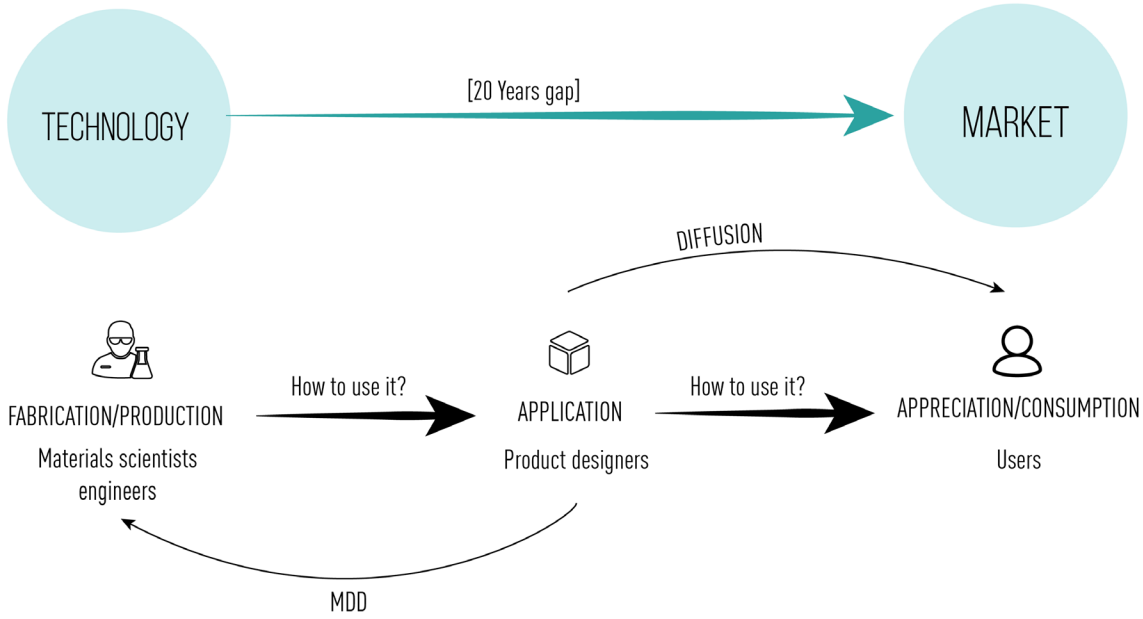


Figure 6. Traditional material development from technology to market

This perspective of material development is a linear process that mainly appreciates materials for their application potential, limiting their active role in shaping social and cultural practices (Camere & Karana, 2018). Additionally, it constrains the potential of materials and misses the potential of acquiring meaning by users.
Eagar (1995) highlights that the gap between material fabrication and successful introduction in the market can be up to 20 years mainly due to a lack of communication between the actors in the process of development, application and use (appreciation). As the developers are unable to communicate the potentials, product designers tend to find applications based on the use of old materials, and users cannot find meaning. According to Karana & Hekkert (2010) the concept of meaning requires understanding of how people experience materials in daily life what is key for material selection processes, considering that material meaning is built in the relationships between User, Material and Product. There is a gap in bridging actors and blurry the barriers between the three moments of material development to reach the potential of materials, in their form, function, and experience.

Recently, emerging approaches in fabrication and applications are addressing this gap in academic studies and social movements. Examples are material-driven design (MDD) where designers are involved in discovering novel properties of a material (Barati & Karana, 2019) and makers movements such us DIY materials (Rognoli et al., 2015) and hacked materials. Still, relatively little is known about how social and cultural practices develop within the experience of materials (Giaccardi & Karana, 2015). Additionally, a material experience framework shown in figure 7 is broadening the material studies by deepening in the relation People, Material, and Practice.

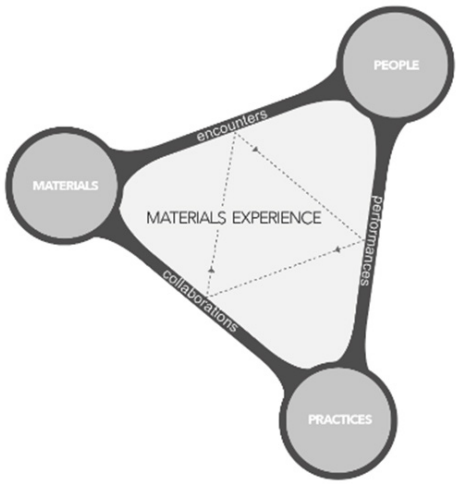


Figure 7. Material experience framework. Source: Giaccardi & Karana (2015)

'Materials experience' acknowledges the experience that people have with and through materials. Figure 8 presents the material experience framework (Giaccardi & Karana, 2015), it seeks to understand how people create meaning through material interactions. Furthermore, this framework helps to understand how these interactions unfold and transform personal and social life.
Regardless, the emerging studies about materials and their relation with users shaping social practices, it is still not clear how this knowledge contributes or interacts in the sustainability field. Sauerwein et al. (2017) mention how the growth of sustainable product design has led to the use of alternative materials (e.g., materials derived from waste, biomaterials, etc.) as substitutes to regular petroleum-based ones, however, are limited to niche user groups in societies. There is a gap in the diffusion and adoption of materials as innovations.

DIFFUSION OF INNOVATIONS THEORY

Traditional diffusion of innovation research broadly focuses on understanding what drives the adoption of novel solutions (Vargo et al. 2020). Furthermore, radical innovations such as new biomaterials are discontinuous innovations highly uncertain and unfamiliar for consumers which increase their resistance to change and decrease options to understand their usefulness. Those require customers to change or adapt their behaviour patterns (Dahl & Hoeffler, 2004; Danneels & Kleinschmidt, 2001; Moreau, Lehman, & Markman, 2001).

The diffusion of innovation theory proposed by Rogers has been one of the most wide-spread innovation theories about user acceptance and adoption (Upham et al. 2020). Diffusion of innovation theory analyses the relevance and process that has to be done for an innovation to enter and diffuse in the market through the innovation adoption cycle. Traditionally, Roger's theory of diffusion argues how the adoption of an innovation is influenced by the innovative characteristics of individual actors and the attributes of the innovation. More recently aspects as network patterns and characteristics of the system are also considered. (Rogers, 2003)

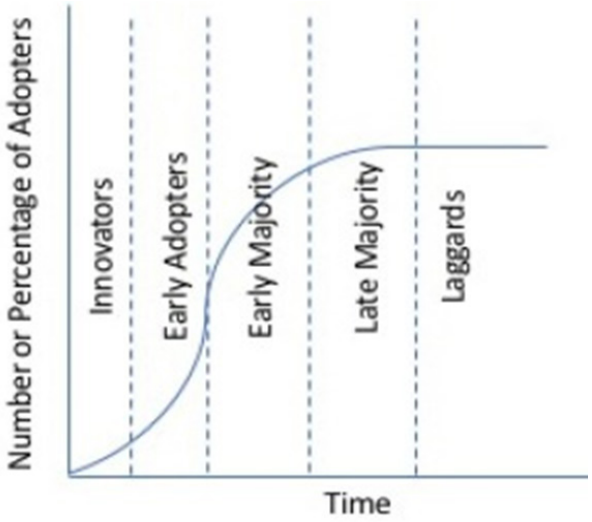


Figure 8. Roger's theory of adoption of innovation. Source. Vargo et al. (2020)

The figure 8 presented by Vargo et al. (2020) shows the classification of adopters according to their innovativeness: Innovators, early adopters, early majority, late majority, and laggards. The S curve represents how the adoption occurs over time.

According to Rogers (2003) even when innovators and early adopters are critical enablers of diffusion of innovation, the adoption is influenced as well by the attributes of the innovation, such as relative advantage, compatibility of the new idea with the values, beliefs, and needs of adopters, and complexity of an idea or product. Additionally, the role of networks representing socio-technical systems evidences a shift to diffusion of innovations as a social process closely related to the context. (Vargo et al. 2020)

According to Roger's diffusion theory, the main moment for diffusion is when an innovation crosses the chasm and it is adopted by the early majority. Once the innovation cross, it diffuses, which still has to be achieved in the material transition. Current biomaterials are adopted by innovators and early adopters.

Vargo et al. (2020) stand a critic in how diffusion is often studied apart from innovations and how in diffusion, usually technology and market are separate in the process, creating a duality between offer and demand that does not reflect the complexity of dynamics in a social context.

CONCEPTUAL FRAMEWORK

Discussion

The biomaterial transition towards a sustainability transition was addressed considering three topics during the literature review: Transition theory, Diffusion of innovations, and Materials. Those theories tend to overlap but mainly complement each other in relation to the research question. Additionally, by merging them, it is possible to fill the gaps than otherwise individually they leave open. This can lead to broader the fields of transition design and material experience, furthermore to find practical solutions to remaining sustainable problems and for the seek of this project, accelerating the biomaterials transition.

Materials literature defines new materials as radical innovations (Karana et al. 2018), and emphasises the role of materials in shaping social and cultural practices, by finding meaning in the relation people, material and practice, defined as material experience. Recent approaches such as MDD (Karana et al. 2018) dive in how to capitalise this role for the material development. However, material theories lack considerations about their diffusion and adoption in markets and does not shift the linear approach of material development from technology to market.

Diffusion of innovation addresses processes of adoption considering the innovativeness of users and attributes of the invention that can be seen as material meanings. Additionally, this theory addresses the diffusion of radical innovations and highlights barriers and strategies to enable their adoption. Even though more recent literature are adding variables such us network patterns and systems, still, diffusion of innovation theory fails to understand the influence of adoption towards a transition. Besides that, as presented by Cramer (2020) diffusion of innovation theory lacks sustainable scope and methods for deliberately influence socio-technical change. Recent literature (Rogers 2003; Vargo et al. 2020) presents the need to bridge gaps between technology and market, and between actors, on one side innovator/producer and on the other side adopter/consumer. Transition theory offers a big picture of a system in a MLP and allows to analyse the dynamics that lock-in an actual regime, as well as patterns of change that can destabilise it towards a more sustainable future.

This theory addresses transitions as radical changes. According to Farla et al. (2012), there is a systemic and interrelated nature between innovation processes and socio-technical transitions that emphasize the importance of actor-oriented and agency-sensitive analysis (Upham et al. 2020). Recent literature proposes a change in the approach from the usual top-down strategies to more bottom-up ones where niches are transition arenas for radical innovations that might be connected and empowered to create new dynamics in a regime level. However, the main critic is the lack of practical approach to support the transitions that in practice face resistance of markets and as radical innovations usually fail to be largely adopted and diffused. Additionally, materials experience literature can add value by deepening in the material practice. For instance, this project proposes to integrate the three theories by articulating the material experience framework (Giaccardi & Karana, 2015) with the framework of sustainable practices in a niche level (Rauschmayer et al. 2015). Finally, by articulating adoption cycles to empower and scale-up the radical innovation. Figure 9 visualises the differences and connections between the 3 topics and merges their approaches to address radical innovations in socio-technical transitions.

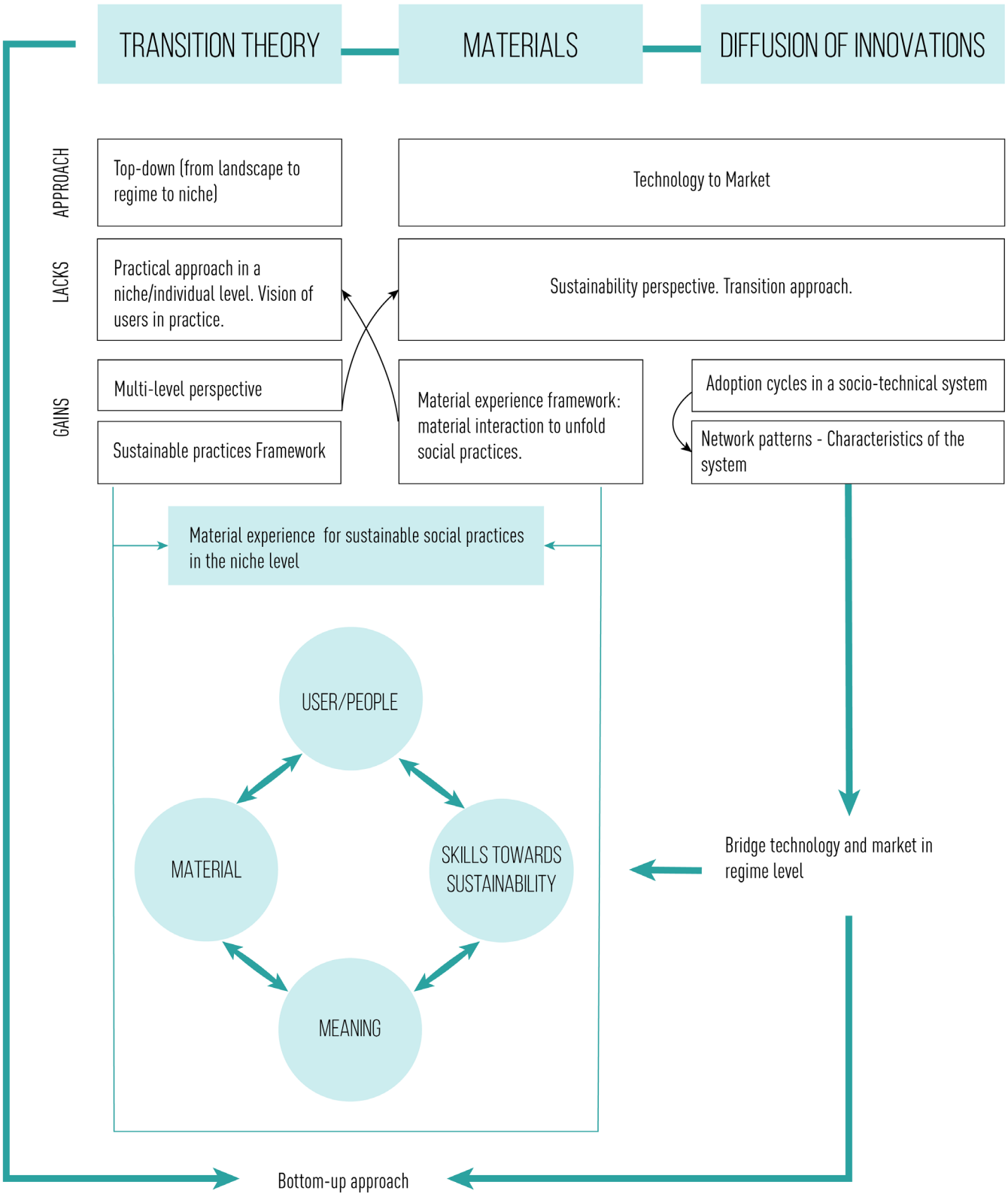


Figure 9. Conceptual framework of the research project. Merge literature in Transition Theory, Diffusion of innovation and Materials.

TAKE AWAY

Chapter 2 presented a literature review about three topics: Transition theory, diffusion of innovations and materials

Overall, the literature has increased in the last years but lacks connection between the three main topics that the research project attempts to connect for a more practical approach to the sustainability problems. The three topics together create the conceptual framework and complement each other.

The conceptual framework frames the following development of the project. Furthermore, three empirical stages were conducted to gain practical information on the biomaterial transition. Those will independently be presented in chapters 3 to 5, however the overall rational behind the stages is introduced afterward. Furthermore, chapter 6 will merge the literature and the studies to answer the research question.

Rational behind stages

Three stages were settled each focused on one of the three goals of the transition theory: describe, interpret and support the transition.

Overall, the aim of this process is firstly, identify dynamics describing look-in patterns and patterns of change in the actual regime. Secondly identify motivation behind the disruptive innovations in the niche level to finally support them, by empowering, managing and mainstreaming them. Figure 10 presents the structure of the empirical study according to the rational.

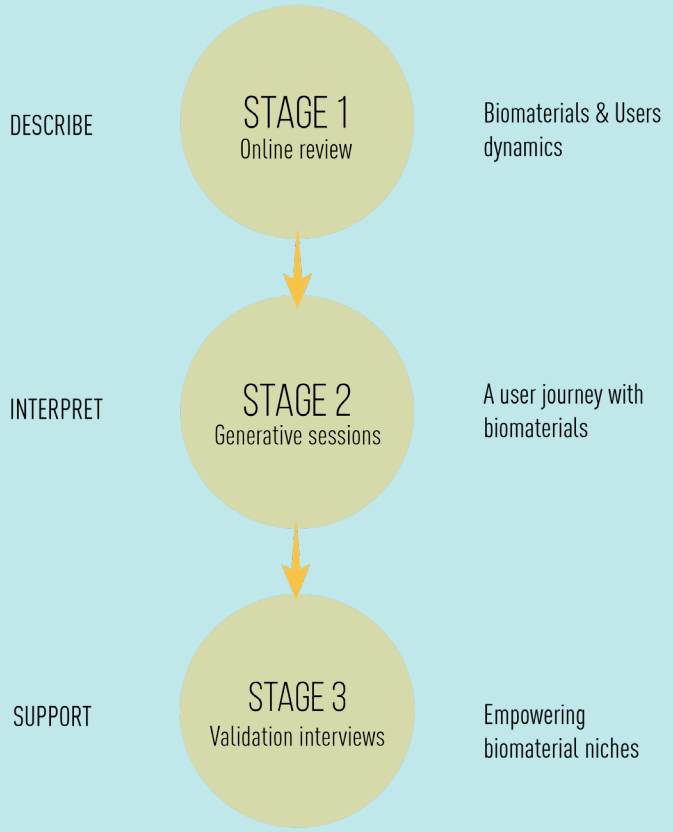


Figure 10. Structure of the empirical study conducted in three stages

CHAPTER 3

Biomaterials &

Stage 1. Online review

User dynamics

This chapter presents the first stage of the empirical study in terms of purpose, methods, analysis of data and results. In the end, it will be presented a discussion section for this chapter.

Stage 1 focused on identifying user & biomaterial dynamics describing look-in patterns and patterns of change in the actual regime through an online review of user comments about available bio-based products.

This stage started independently to later finalise in parallel to the second stage as visualised in figure 3, in order to analyse the data from users as a conglomerate.

The results of this stage include 130 comments of users about 11 bio-based products currently available in the market.

PURPOSE

According to the transition theory, one goal of transition research is to describe the transition. In stage 1, a systematic online review of comments about available bio-based products in the market was developed aimed to dive in the niche/individual level and find current biomaterial and user dynamics.

By exploring biomaterial and user dynamics. This stage seeks for identifying lock-in patterns describing the actual regime, and patterns of change as rooms for radical innovations.

Internet culture and user generated content

The internet has ignited social dynamics in an online world and offers the opportunity to picture consumption dynamics within the market. Currently, the online presence for companies and brands is as important or sometimes even more than the offline presence. Online channels had opened an opportunity to engage directly with people, allowing them to create content.

In research from Jacobs et al. (2015) a more active role of users is related to online channels and social media, highlighting how internet culture has increasingly been customized to the creation of content by each individual user and a new emphasis on user-generated content is shaping cultural and marketing dynamics.

Furthermore, research methods such as netnography and online communities that rely on online data are gaining more importance in qualitative research (Kozinets, 2015). Some benefits are the low cost and availability of rich data from several actors. However, a challenge to overcome is the filter bubble (Pariser, 2012) that this project avoided by exploring directly different channels instead of using search engine services such as Google Search.

METHODS

The review started in an exploratory manner. It was initially determined to include a wide range of product categories, actors and channels to avoid bias pre-selecting some of them. However, during the development, the range naturally narrowed down according to two criteria: the material of the product and the availability of comments.

Firstly, the material was considered according to the classification of material selection for sustainable products presented by Camere & Karana (2018) including materials made from renewable resources (bio-based) and based on biotechnologies or biofabrication. However, well-known biomaterials were not considered such as cotton, linen, bamboo or wood, because those belong already to the massive market. Additionally, the project has a focus on the future and

Type		***Channel***
Internal	Owned by the brand or material developer	Official website and social media Kickstarter
External	Owned by people	Blogs (about a product category) YouTube Reddit
Hybrid	Owned by influencer or domain curators	Specialized design websites (Deezeen) Specialized blogs (suistainablejumgle.com) Apps (blank.paris) TED Talks

Table 1. Channels explored during Stage 1

the introduction of new materials into the market, for instance, novel biomaterials were the scope.

Secondly, the availability of comments was determinative to consider the product in the review. The search was conducted crossing different channels to avoid the filter bubble (Pariser, 2012), it was developed through mainly three kinds of channels, internal, external and hybrid, classified according to the nature of the actor creating the content. ***Internal:*** owned by the brand or material developer; ***external:*** owned by people and ***hybrid:*** owned by influencers or domain curators. In total 8 channels were explored as shown in table 1.

The online review developed in two steps, finding the bio-based products and finding the user comments. Firstly, hybrid channels (suistainablejumgle.com, dezeen.com, blank.paris) were explored to find the available products based on the material. Secondly, the search for user comments about each product started in internal channels (official websites and social media), however, the comments were usually scarce but for the Kickstarter channel. Thirdly, the search continued in external channels where people participated more (Blogs, YouTube and Reedit).

Finally, 118 comments were reviewed about 11 products. The comments were registered to furthermore being analysed. Appendix A gives an overview of the data collected. Figure 11 visualises how the online review was conducted and the outcomes of the two main steps.

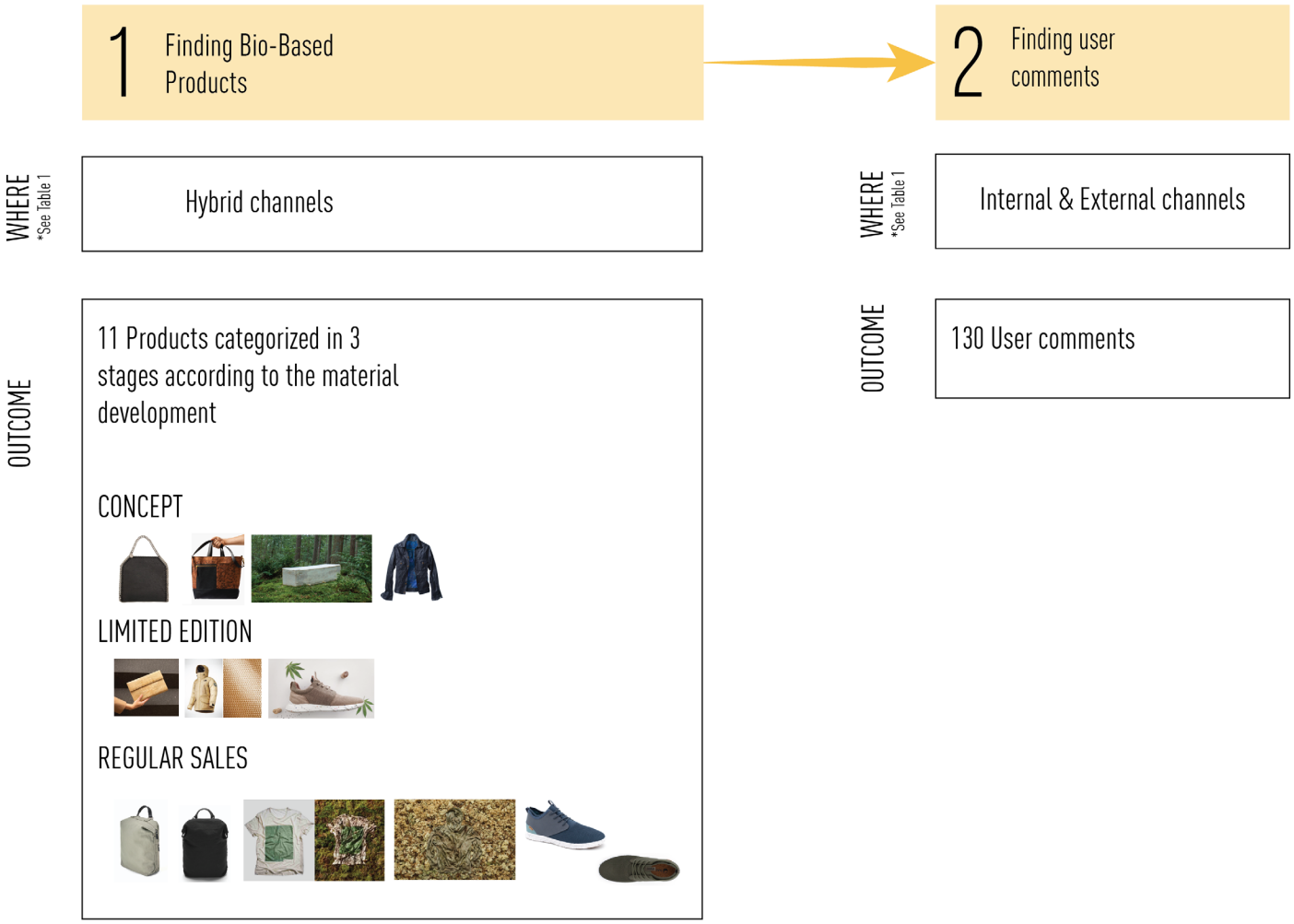


Figure 11. Development of online review conducted during Stage 1 including channels and outcomes

Analysis of the data

During the development of the online review until narrowing down the products and comments, observations about the actual regime were registered in a notebook (as ethnographic diary) and several tables shown in Appendix B. The collection of data (observations and comments) stopped when saturation was reached and no more new findings were rising from the data.

In this stage, the analysing of data was developed considering that in sustainability transitions innovations should not being seen as 'the solution' or 'means to an end' but rather as emerging experimental processes that generate insights into desired transition pathways and the barriers to these transitions (Loorbach et al. 2020). In other words, observations were focus on finding the insight behind, identifying lock-in patterns and patterns of change.

Moreover, observations were analysed in terms of relevant actors and relations between them, possible niches and their dynamics, and stage of development of bio-based products in order to understand the actual market. On the other side, the comments were categorised according to their topic to revel people's focus.

Additionally, the comments were further analysed with the outcomes of stage 2 as a conglomerate of data from users, this analysis and outcomes will be addressed in the following chapter.

RESULTS

Overall, the online review was rich in vision, concepts and ideas about biomaterials in the future, however, there are few examples of novel bio-based products currently available in the market. Those products are in a niche market, targeting people in the high income segment. The availability of comments of people are related to the development of the material.

The current offer of bio-based products in the market as found during the online review was classified in three stages of development: Concept product, limited edition, and regular sales. Table 2 presents the final 11 bio-based products found with comments of users. Additionally, the table shows their material, brand or material developer, and the amount of comments of users reviewed. In total 118 comments were found and analysed in the present and following chapter.

The main part of the available offer is in the concept product level lead, usually the material and product category are more novel such as the Bacterial cellulose cloth by BioCouture-Suzanne Lee or the Algae bottle by Ari Jonsson. The limited edition level refers mainly to MVPs releases in small scale with the goal of testing the product or validating the market, some examples are the Moon Parka made of brewed Protein by Spiber & the North face, or the DopeKicks shoes made of hemp fiber and released through Kickstarter. Finally, the regular sales level refers to products sell on a regular basis, the materials and product categories are more traditional and are developed by regular brands that expand their portfolio with a sustainable product line, some examples are the backpack made of BananaTex from Qwestion, the T-shirts made of plant-based material and dyed with algae by Vollebak, and the shoes with algae foam by Saola.

In the stages with more novel materials and products (Limited edition and Concept), the relevant actors for development are start-ups (e.g. Loop, BioCouture-Suzanne Lee, DopeKicks) and collaborations between a large company and a material developer (e.g. Stella McCartney & BoltThreads, Luxtra London & Fruit leather Rotterdam, Spiber & The North face). In the last case, the launch is made by the material developer, for example, in the collaboration between Spiber and The North face for the Moon Parka, the limited edition sales and communication about the product was made in the Spiber channels.

Stage	***Material***	***Product***	***Image***	***Brand***	***Comments***
Concept	Bacterial cellulose	Clothes		BioCouture by Suzanne Lee	
	Mylo leather	Bag		Stella McCartney & BoltThreads	
	Algae	Bottle		Ari Jonsson	
Limited edition	Mycelium composite	Living cocoon		Loop	1
	Brewed Protein	Moon Parka		Spiber & North face	9
	Hemp Fibers	Sport Shoes		DopeKicks	46
	Mango/Pineapple leather	Bag		Luxtra London & Fruit leather Rotterdam	1
Regular Sales	BananaTex	Backpack		Qwstion	51
	Eucalyptus trees dyed with algae	T-shirt		Vollebak	2
	Eucalyptus trees dyed with pomegranate	Hoodie		Vollebak	4
	Algae foam	Sport Shoes		Saola & Bloom foam	4

Table 2. Results of the online review in Stage 1

The main outcome of this stage is a map of biomaterials & users dynamics in the actual regime as patterns of change. According to the research question, the focus of the analysis was on dynamics where users have an active role, however, more dynamics could be identified as it will be presented in the further research section.

Three dynamics were found: New role of users in material development, Users creating content for diffusion, and A more active role of users in the land-scape. Figure 12 visualises those dynamics in relation to the actual regime. Additionally, the following section (chapter discussion) will present the findings in relation to the theory in terms of under covering lock-in patterns.

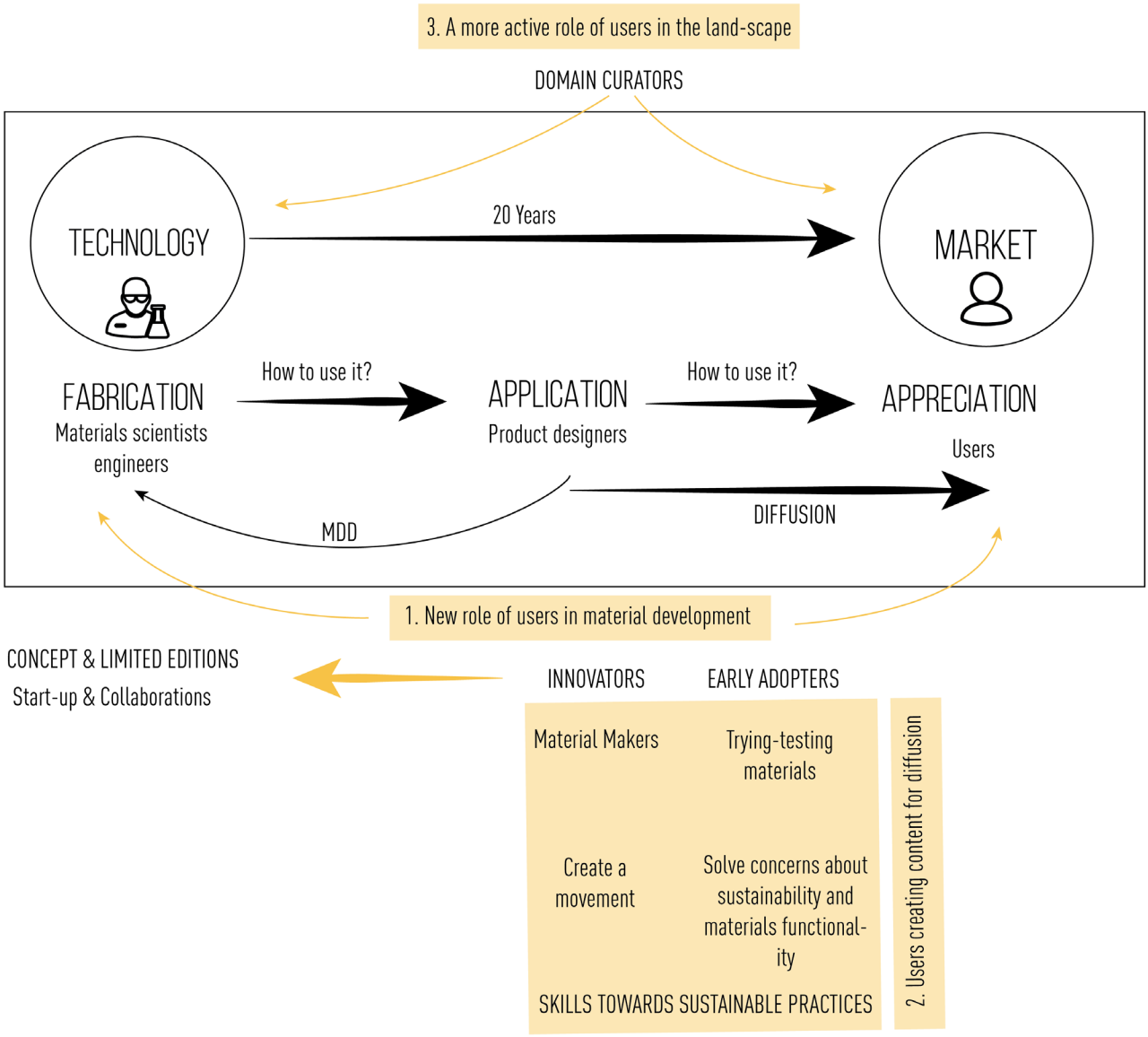


Figure 12. Map of dynamics between biomaterial & users in the actual regime

1. New role of users in material development:
According to the material stage of development, the engagement with users differs and highlights a more active role, blurring boarders within actor and shifting users roles. However, those users are recognised mainly as innovators or early adopters.

For instance, users mainly innovator and early adopters underpinned by online channels are giving feedback to new actors in the material development (start-up and collaborations). Table 2 summarises the relation between the bio-based product development and the engagement of users.

Stage of development	***Actor***	***Example***	***Engagement with users***
Concept	Start-up	Bacterial cellulose cloth by BioCouture-Suzanne Lee	Create a movement (trend) and support meaning creation
Limited edition	Collaboration between a large company and a material developer	Moon Parka made of brewed Protein by Spiber & the North face. The Mylo leather bag by Stella McCartney & Bolt Threads	Feedback product development
Regular sales	Regular brands	BananaTex from Qwestion. T-shirts made of plant-based material and dyed with algae by Vollebak	Reviewing product as a done regularly

Table 3. Bio-based products development and engagement of users

2. User creating content for diffusion:

In general, the focus of the comments of users about the available bio-based products were about product performance, material functionality and sustainability. However, more in depth 6 roles adopted by users were identified according to the content: supporter, domain expert, potential buyer, lifestyle user/influencer, user blogger and product expert. The following table shows the roles adopted by users in relation to potential skills towards sustainability according to the model of Rauschmayer et al. (2015)

Overall, when commenting, the users transit their recognition of the material from uncertainty to solving concerns about its functionality. This might influence the perception of other users that read and serve as a tool in adoption and diffusion cycles.

User roles	***Skills towards sustainability***
Supporter	Understand material development risks and costs
Domain expert	Focus on sustainability. Questioning big picture and discuss the sustainable value of the material
Potential Buyer	Focus on price and benefits
Lifestyle user/influencer	Solving concerns and connects the narrative with her/his lifestyle
User blogger	Explain further sustainable value and product performance. Create and share content
Product expert	Focus on product performance and overall usage experience

Table 4. Roles adopted by users when commenting bio-based products in the online review.

3. A more active role of users in the land-scape:

Users are adopting a new role in a land-scape level, acting as intermediaries, labelled for the project as domain curators (Blank.Paris). These users are aimed to connect production and consumption sides to regulate the available offer as a curator and wide-spread knowledge for a sustainable future.

They can fulfill an independent and mediating role in establishing innovative collaboration between businesses (Cramer, 2020).

CHAPTER DISCUSSION

Stage 1 aimed to describe the actual regime was useful to validate the finding in the theory about the actual regime. The online review was a good method to identify the lock-in patters suggested for the theory and the patterns of change previously described as users and biomaterials dynamics.

Rauschmayer et al. (2015) states that existing regimes are characterized by lock-in and path dependence, usually are oriented towards incremental innovation along predictable trajectories. Such is the case of the biomaterial transition facing several barriers for adoption and diffusion as usually innovations face.

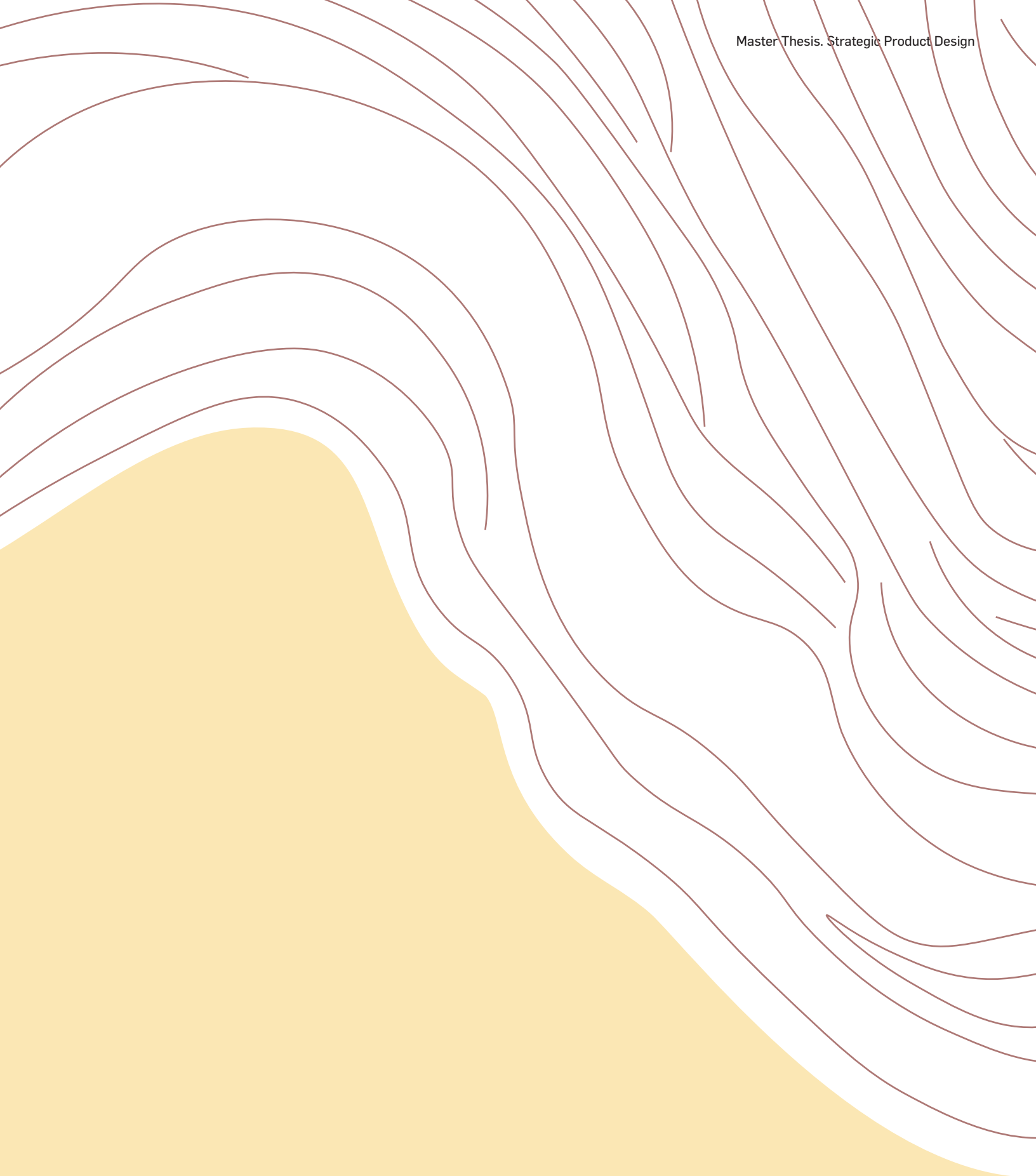
Biomaterial development follows the linear process from fabrication (technology) to appreciation (market), as it can be seen in the cycle: Concept, Limited edition and Regular Sales observed in the development of the available bio-based products.

Lock-in patterns affect innovations that get trapped reinforcing the current regimen instead of transitioning to a new one. According to the results in stage 1, five lock-in patters were identified. Table 5 presents the lock-in patterns with a description and a power quote from the comments to exemplify their meaning.

Lock-in Pattern	***Description***	***Example***
1. *A biomaterial does not lead to a more sustainable behaviour due to market dynamics*	There is a dramatic reduction in the sustainability topic after purchase/use. People initially buy because the product is sustainable and later one buy more to have all colours, references and styles. In the same way, brands developed the material and story behind because of the sustainable impact, afterward they follow regular marketing strategies to sell more.	"bought the first version of these snickers/"kicks" for me last year and I loved them ! Then I bought for my dad for Christmas, he loved it as well! I was amazed by the product so I got the black snickers for work" quote from comments.
2. *A biomaterial perse does not lead to reduce impact in the environment after the product is consumed*	Brand or developers does not communicate how to dispose the product according to the material or how long the product will last.	"Product lifecycles need to be considered too... it's obvious that "sustainability" is a term used either as cost saving or sales boosting measure at best" quote from comments.
3. *A bio-based product is not meant to certain targets*	There are several assumptions about audience of bio-based products, some related with the lifestyle.	*"It is for the pees who live and breathe design"* quote from comments.
4. *A biomaterial is not accessible because of price*	Biomaterials are associated to elite prices and bio-based product more as luxury items.	"I personally think it should be in the $200-$500 range, however we live in a world where idiots spend $1000 on sneakers and sweatshirts, so comparatively this is a bargain" quote from comments, "He talks a lot about the fabric as a sales man. This must be expensive" quote from comments.
5. *A biomaterial is assessed comparing to an old material*	Literature suggest the comparison of new materials to old material delay reaching the full potential of the material. Additionally, even though, this is an strategy to overcome adoption barriers, it can lead to incremental innovations in lock-in patters, so, no new meaning is created.	"I am a bit scared that the fabric could get dirty a bit too easily - and slightly worried it's not going to perform as well as the "Petrol based" counterparts" quote from comments.

Table 5. Lock-in patterns

Furthermore, the three patterns of change identified as user & biomaterials dynamics (New role of users in material development, Users creating content for diffusion, and A more active role of users in the land-scape) have the potential to break the lock-in patterns and destabilise the actual regimen towards the bio-based future. However, it doesn't mean that the transition is actually happening, the patterns of change need to be supported and scaling-up to successfully achieve changes. The following stages will focus on finding motivations behind this patterns of change and ways to support the innovation in the niche level.



TAKE AWAY

Chapter 3 presented the first stage of the empirical study. It developed through an online review of comments of users about available bio-based products in the market. It had the goal of mapping the dynamics inside the actual regime to identify lock-in patterns and patterns of change. Some gaps were discovered about motivations behind and capabilities towards sustainability. Those will be explored in the next stage and chapter.

Three dynamics were found: New role of users in material development, Users creating content for diffusion, and A more active role of users in the landscape.

The data collected was rich and abundant. It was possible to observe dynamics between stakeholder that go beyond the research question addressed in this thesis. There is a potential for further research to use methods based on online data.

Finally, the findings lead to the design of tools and methods of the following stages. Specifically, the design of booklets and activities in stage 2 and the selection of participants in stage 3.

CHAPTER 4

A user journey w

Stage 2. Generative sessions

with biomaterials

This chapter presents the second empirical stage in terms of its purpose, methods, analysis of data and results. In the end, it will be presented a discussion section for this chapter and a take away for the following one.

Stage 2 drew a user journey with biomaterials based on users' dimensions and narratives during generative sessions to undercover motivations behind the disruptive innovations in the niche level. The previous stage described in chapter 3 had the goal of describing the dynamics between biomaterial and user. According to the transition theory a following up activity would be to interpret the reasons behind those dynamics.

The results of this stage are a user journey, dimensions describing the user perception of the biomaterial transition and the future envisioned by users. The dimensions are the result of the analysis of data from users gathered during stage 1 (comments) and stage 2 (booklets and groups sessions).

PURPOSE

The second stage sought for a more direct connection with the users, to find motivations behind certain patterns of change and capabilities towards sustainability. The proposed methods focused on connecting deeply with emotions and narratives. Additionally, this stage was a convergent moment to validate the findings in stage 1 adding a more personal level, which was gained through generative sessions.

Narratives

During this stage, narratives were the main mean to gain insights from the participants, the tasks and activities looked for the construction of them around biomaterials and bio-based products.

Narratives allow gaining more in-depth information and implicit insights from people, additionally, those contribute to define meaning and value of a material artefact (Giaccardi & Karana, 2015). Furthermore, the process of creating and writing narratives allowed the participants to transport themselves by creating a scene were a certain experience occurs (Hende & Schoormans, 2012). This enhance emotions, meaning and deeper understanding of an experience.

METHODS

This stage was a generative study with 2 parts named “materials around” to avoid creating a direct connection to bio-based materials that might lead or biased the participation. During the first part, a sensitizing booklet was developed individually to understand the relationship between user and material. Secondly, group sessions were held to discuss and elaborate narratives about bio-based products.

Generative sessions are done as design practices to map the context around a user experience and are useful to learn about needs, wishes and motivations of the people involved (Sanders & Stappers, 2013). Furthermore, generative sessions help to make the implicit more explicit, gaining knowledge about latent needs.

The study was developed with 15 participants in an age range between 25-35 years. Sampling reached a diverse group according to their gender, level of education and ethnic background. According to the diffusion of innovation theory, the goal of the sampling was to reach people in the other side of the chasm, so, the selection avoided designers and people with a recognisable passion for sustainability, those that in stage 1 were identified as innovators or early adopters.

Table 6 summarises the characteristics of the sample.

Gender	Male 8 Female 7
Level of education	PhD 7 Master 3 Bachelor 5
Background	Non-EU 9 EU 6

Table 6. Sample for stage 2. Generative sessions

The sensitizing booklet was an individual assignment developed over the period of one week, aimed to make participants aware of the materials around and their way to assess the sustainability of a product, also preparing them to hold the second session and to start creating some narratives. Participants completed 6 small tasks about the most sustainable product used in a daily basis according to the material. The design of the booklet followed the levels of engagement and interaction presented in the Material experience toolkit: sensorial, interpretative, affective, and performative (Camere & Karana, 2018).

The group sessions were held online for 60 minutes with 3 participants and the researcher as the facilitator. The sessions developed following a presentation and a booklet through three moments: intro/recap of the sensitizing booklet, role game to write down stories, and a wrapping-up discussion about the research question. Appendix C shows the booklets used for both moments.

During the group session, the main activity was the role game where each participant adopted a role to write down a brief story about a bio-based product suggested for the facilitator. This activity developed in three moments, firstly participants were assigned with a role to write down a brief story, secondly they shared their stories and commented about them and thirdly they finalised their stories after the feedback. Figure 13 shows the timeline of the session.

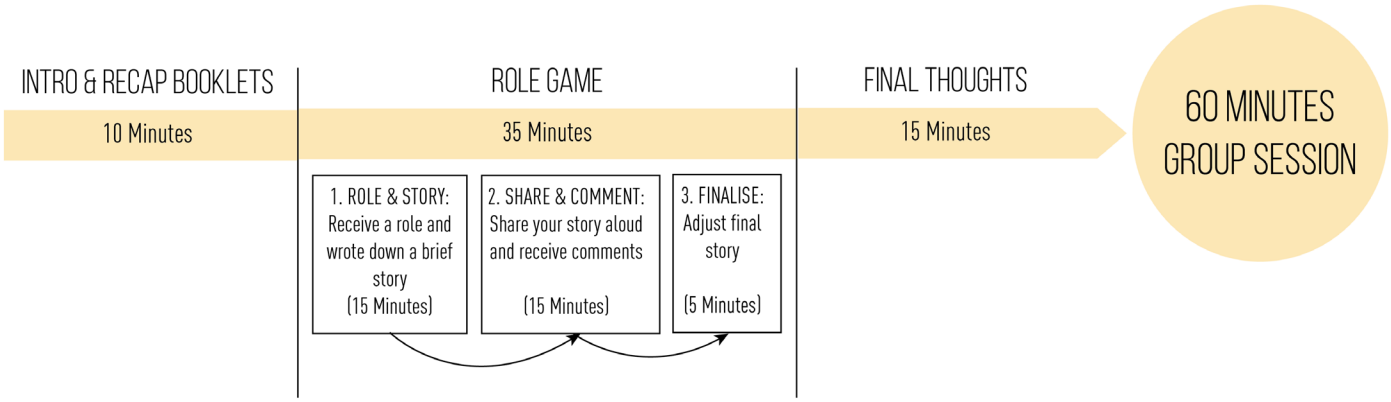


Figure 13. Session 2 (group sessions) Timeline

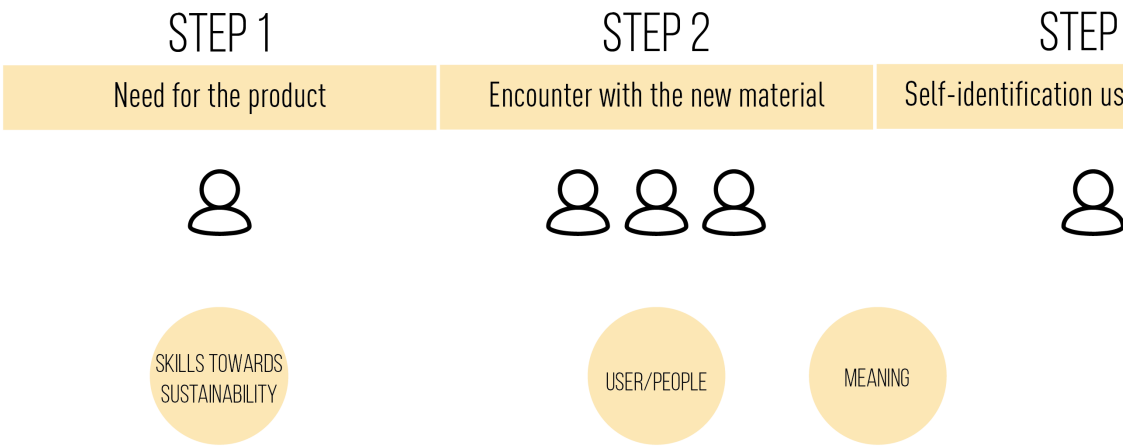
The role game was designed based on inputs from stage 1, the bio-based product and the role of participants. The 5 products with more comments were selected from the review in stage 1, those were presented giving a basic description to not lead the outcome as shown in the following example in figure 14. On the other side, the roles assigned to each participant were selected according to the focus adopted by users when commenting in stage 1: users focus on product performance, material functionality and sustainability. Those roles remained the same trough out the 5 sessions and were assigned pursuing a connection to the information registered by participants in the sensitising booklet.

Figure 14. Example of bio-based product presented during group session 1 of the Stage 2.

Five meetings were held and 15 brief stories were written in total. Table 7 presents a summary of the sessions, showing the sessions, materials individually selected for the participants in the sensitising booklet and the bio-based product assessed. Additionally, the stories are presented in Appendix D.

Group Session	***Materials selected by users in sensitizing booklet***	***Product used during the session***	
1	Glass Recycled polyester Second hand leather and wood	Bananatex	
2	Fabric (eco-cotton) Stainless steel Wood	Hemp	
3	Fabric Stainless steel Glass	Lyocell and algae dying	 
4	Fabric Wood	Brewed protein	 
5	Recycled plastic Beeswax Luffa	Algae foam	

Table 7. Summary of group sessions in Stage 2: Materials and bio-based products assessed



Analysis of the data

Stage 1 and 2 finalised simultaneously as shown in the first chapter (figure 3) to create a conglomerate of data from users to analyse according to the conceptual framework of the project presented in chapter 2 (figure 10). The data analysing was done according to the grounded theory method from observations to theory (Spencer et al., 2014) and using Atlas.ti to facilitate the process.

In order to identify the dimensions describing the perception of users about the biomaterial transition, the comments from stage 1, booklets and group sessions from stage 2 were coded following three steps: Initial coding, focused coding and categories definition. Additionally, a previous step to start coding the data was prepare it, the content in booklets was unified in one file according to the question and the five group sessions were recorded and transcribed to analyse them.

Initial coding was done in-vivo so that the exact wording of the participants and reviewers would not get lost and later those were categorised in focused codes. The initial codes were divided over 39 focused codes which were all labelled and following up, these were classified over 12 subcategories belonging to 6 dimensions to describe the user perception of the biomaterial transition. For an overview of the coding process see appendix E, and for the codebook see appendix F.

On the other side, to analyse the data in a more abstract level looking for motivations behind the patters of change found in stage 1, a user journey with biomaterials was drawn based on the 15 stories written for the users in the group session. An overview of the stories can be seen in Appendix D.

Figure 15 presents the journey. In total 6 steps were found in the relation biomaterial and user: need for the product, encounter with material, personal assessment using the product, material and product assessment, assess sustainability big picture and impact.

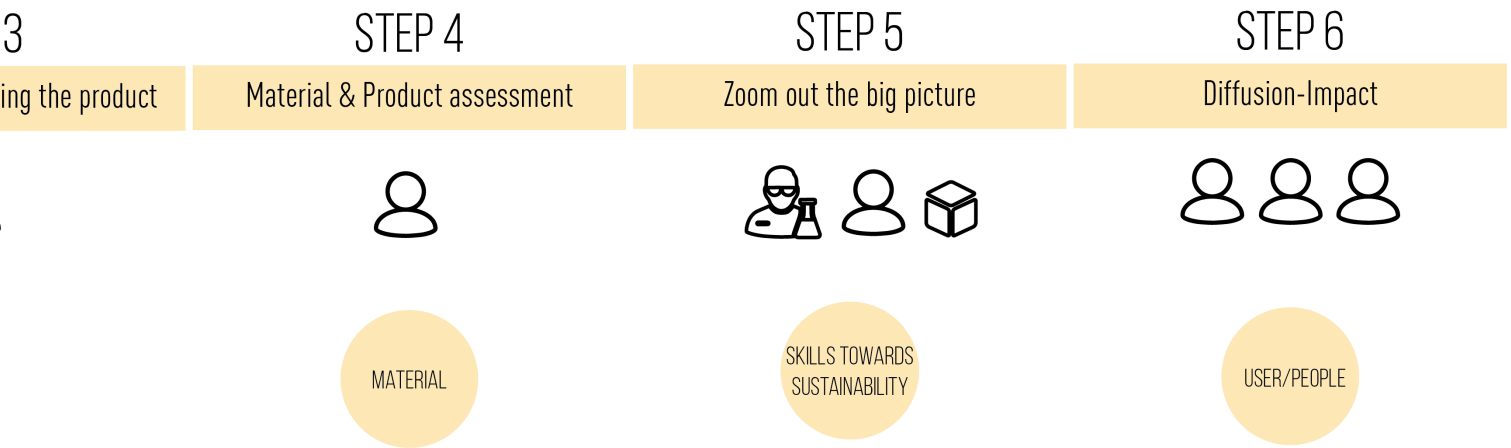


Figure 15. Biomaterials and user journey

RESULTS

The results of this stage are a user journey with biomaterials, dimensions describing the user perceptions of the biomaterial transition and the future envisioned by users.

The dimensions are the result of the analysis of data from users gathered during stage 1 (comments) and stage 2 (booklets and groups sessions).

This journey helps to gain motivations behind the three dynamics found in the previous chapter between users and biomaterials: New role of users in material development, Users creating content for diffusion, and A more active role of users in the land-scape.

Journey map and patterns of change

Figure 15 presented the journey with biomaterials with 6 steps. Table 8 presents power quotes from different stories exemplifying the steps in the user and biomaterial journey.

Step	***Label***	***Quote***
1	Need for the product	“For my ski trip next year I am interested in buying a parka. Because I will be skiing, it is important that the parka does not get damaged easily by water/snow, stained by dirt or wears or tears after prolonged (possibly) abrasive use. Furthermore, it should be lightweight. It should also retain its characteristics after taking it out of storage on a yearly basis (i.e. no degradation of material)” Participant 11. Group session 3
2	Encounter with material	“I first got to know DopeKicks shoes via a really good friend of mine, she is very engaged to sustainability and recommended me this product as new trend in the market” Participant 4. Group session 2
3	Personal assessment using the product	“First was the social aspect, it made me feel cool and alternative…at last I was unhooked from the big fashion retailers.” Participant 9. Group session 3
4	Material and product assessment	“I found them very fresh and cool, even walking in the Italian summer for hours. The natural material makes the foot breath and I really appreciate it since I can’t wear sandals. Also, the cork sole is very comfortable” Participant 6. Group session 2
5	Assess sustainability big picture	“It was also important that the value chain involved in the product apart from the material itself fits with the sustainability image” Participant 1. Group session 1
6	Diffusion-Impact	“Is great, I use to use this T-shirt in my teams meetings, you know we educate through the example. In the way this product become popular, its price will reduce and its process of manufacturing will improve.” Participant 8. Group session 3

Table 8. Quotes from participants in user journey steps.

Dimensions

Six dimensions to describe the user perception of bio materials transition were found after stages 1 and 2. Those are material meaning, assessment of sustainable materials, market values, social influence, participation and tracking the transition. In the chapter discussion, these dimensions will be related to the conceptual framework from the literature.

Table 9 shows the dimensions with a description, subcategories, focused codes inside each and a power quote to better understand their meaning.

Dimension	***Description***	***Subcategory***	***Focused Code***	***Quote***
Material meaning	Engaging with a new material. Get to know it through sensorial and functional properties	Recognition of material	Bio-based association	Because it is a natural material, care has to be taken when washing it. Participant 11. Booklet.
			Consciousness about material	As consumers we also use a lot of materials. And from there it's if you're slightly educated about these things, you know, kind of which are the good one and which are the bas ones. Participant 1. Group session 1
			Material selection based on use	It depend on the use case. Comments
			Sensorial property of the material	The material has a nice grip. I like how is slightly changing. Comments
			Understanding the new material by comparing it to a known material	I think the banana backpack ends up being similar to other natural fibers like jute. Participant 2. Group session 1
		Challenge for new bio material	Concerns about material performance	I am a bit scared that the fabric could get dirty a bit too easily - and slightly worried it's not going to perform as well as the "Petrol based "counterparts. Comments
			No material meaning-association	If I want to throw away the T shirt, should it be the same as with a regular T shirt?. Participant 8. Group session 3
Assessment of sustainable materials	What people need to know to appreciate sustainability in a material, and to assess the bio material cycle source/process/end-of-life	Sustainability knowledge	Concerns about sustainable performance	Product lifecycles need to be considered too... it's obvious that "sustainability" is a term used either as cost saving or sales boosting measure at best. Comments

Dimension	*Description*	*Subcategory*	*Focused Code*	*Quote*
			Hard to assess a sustainable material	It seems very hard to assess a material once we start thinking of its whole lifecycle because it involves many other processes..... I am not sure if there is one truly sustainable and how we can assess that. Participant 12. Booklet
			Knowledge needed to appreciate material and sustainability	It's not until you view it through a sustainable lens that you get a strong appreciation of the thought and care behind every detail. Comments
			Importance of durability (paradigm sustainable=durable)	I usually tend to look for shoes that last quite long and usually technical materials provide this. To me, doesn't seem to be shoes that can last really long because probably for the materials.... You cannot watch that many times those kind of materials. Participant 6. Group session 2
			Sustainability association	Plant-base material require less energy to grow. Comments
		Sustainable behaviour	My product is like helping nature	My second hand dinner table is helping nature because there is no need of more wood to do it. Participant 3. Group session 1
			Sustainable personal consistency	I like the idea of wearing something that can represent myself in my way of viewing the world. I also like the idea to decrease my carbon footprint in any aspect of my life. Participant 5. Group session 2
Market values	Importance of the material for the purchase assessment. Mindset about price & value of product and material	Price and value assessment	Cheaper because it's recycled material	I saw the label saying that it was made from recycled material and I was, like, okay, maybe that's why it's a bit cheaper
			More expensive more mindful	They (natural materials) might also be a bit more expensive but you gain benefit from long use. Participant 11. Booklet
			Novelty of the material, assumption is expensive	He talks a lot about the fabric as a sales man. This must be expensive. Comments
			Market Price (influenced by people choices)	Í personally think it should be in the $200-$500 range, however we live in a world where idiots spend $1000 on sneakers and sweatshirts, so comparatively this is a bargain. Comments
			Value more than the material (price)	At that price, it need to be more than a great fabric. Comments

Dimension	***Description***	***Subcategory***	***Focused Code***	***Quote***
Social influence	Within users communication for Self-identification, Social validation and Word of month	Send a message	Being seen as cool and alternative	First was the social aspect. It made me feel cool and alternative. At least I was unhooked from the big fashion retailers. Participant 7. Group 3
			Share with the world	Use the T shirt as a conversation piece to start to create conversation with other people. Participant 9. Group session 3
			Spark the fire	So, that when I say the shoes are made from algae, and then they are like, No way I don't believe it. I got them intrigued as well and then, I, like, spark the fire in them. Participant 13. Group session 5
		Following peers	Knowing the material because of someone else	I first learned about them with my mom. Participant 4. Booklet
			Looking for social validation and recommendation	I was just looking online, just seeing what people are saying what's possible, what kind of alternatives there are out there. Participant 11. Group session 4
		Teaching others	Showing how/when to use it	What I want to say is like it's good for the day by day activity. Participant 4. Group session 2
			Solving concerns	At first I was concerned that the material wouldn't last long, but I've had it for a few months and it's as if the bag is still brand new. Comments
Participation	Opportunity for co-creation between actors (Active participation in development/policy)	Engagement in product/ material development	Idea for understanding the material	I wish there was a way for manufactures to offer what carpet places do: Sample.... It's difficult to understand trough a video what a fabric feels like. Comments.
			Suggestion for development	I hope they consider Milkweed for insulation instead of cruel. Comments
Tracking the transition	Recognition of transition and different moments, actual, future and in between	Actual scenario	Actual offer is expensive and not affordable	Actual offer is expensive and not affordable. Participant 6. Group session 2
			Having more than one colour (values of consumption)	I bought my first pair in green colour for the summer and I liked it so much, I end up buying later the black version. Comments
			Niche audience and lifestyle assumptions (added value)	It is for the pees who live and breathe design. Comments I guess that can help to catch people who are not as much sustainable as me and convince them to wear. Participant 5. Group session 2

Dimension	*Description*	*Subcategory*	*Focused Code*	*Quote*
		Future regime	Who doesn't want to be sustainable?	Bye bye products that are not sustainable. So, if it provides for you and your needs, why not to do that? If it is in your budget limit. Participant 15. Group session 4
			Deconsumption Need	However good or bright the idea, nothing beats "not producing" sustainability-wise. So, the ultimate way of sustainable design is managing to eliminate the need for that product in the first place. Comments
			Future sustainable scenario	In order to shift towards a less harmful industry globally we are going to need to lower production volumes and increase product life. Comments
		Transition	Personal assessment of product (material, benefit, use)	Shoes fit well, are nice and heavy, super comfortable and are overall the best purchase I've made. Comments
			Unexpected new mind-set	However, little did I know that this gift was to change my dressing style, and drastically! Participant 7. Group session 3
			Understanding the development process (price and need to try products)	I think by now it's too expensive against a normal T shirt. Because it requires from a product that is in innovation Participant 8. Group session 3
			What is important	I think that sustainability in terms of the material should not really come to compromise the functionality of the material. Participant. Group session 1

Table 9. Dimensions describing the user perception of the biomaterial transition

The third result of the second stage lead by the generative sessions was the future envisioned by users.

Envisioning a scenario helps to align individuals/ niches and create a coordinated movement to the same goal. The research sought for uncovering the user perception and co-creating a future vision to support behavioural/cultural changes. It was done by the engagement with participants through the different methods and the analysing of latent needs and desires in the comments.

There is a need of deconsumption and a finding new mind-set created by meanings: Material and products (knowledge and associations) and value in the consumption (Durability / Price).The role of the material is considered based on the functionality of the product. The role of users is more active and the power between the actors in more horizontal, so, users are not the responsible for taking the decisions and more to create and share content.

Future concept vision

What users envision is an evolution of sustainability as added value to a norm.

Figure 16. Images selected by participants in Stage 2

CHAPTER DISCUSSION

Stage 2 drew a user journey with biomaterials based on users' dimensions and narratives during generative sessions to undercover motivations behind the disruptive innovations in the niche level. Following are described some findings in relation with the theory.

Materials such as glass, wood and textile were presented by the participants as the most sustainable. Those materials are not directly related to technology rather to tradition. Additionally, a biomaterial is not immediately associated to sustainability, for instance sustainable products are associated with durability instead bio-based products are associated to the idea that nature is not durable. This creates by default uncertainties about the material performance and sustainability value. *"I usually tend to look for shoes that last quite long and usually technical materials provide this. To me, doesn't seem to be shoes that can last really long because probably for the materials…. You cannot wash that many times those kind of materials"*. Participant 6. Group session 2.

People created narratives supported on other product/material by comparing sensorial properties and functionality with old or known materials. This makes evident the gap between development and meaning in practice. However, the narratives were a nice example of how people create meaning in the relation User/material/product.

The more abstract the material, the more difficult is to assess from the people. For example, session 4 was about the brewed protein material. Participants struggled to find associations to create the narratives. Related to material experience and finding meaning. Instead, the natural component of the material was key to ignite the narratives. It can be due to the associations that participants already have about nature, even if the material is new.

Furthermore, the participants highlighted the limitation of the material in sustainability assessment. The product is assessed as sustainable and the material is part of it. It was difficult for them to define in what degree the material is important for the purchase decision, however, they agreed in the increasing awareness about materials and the need of more information about durability and correct way of dispose the products

Dimensions and theory

Stage 2 presented a list of 6 dimensions describing the user perception of the biomaterial transition. On the other side, the literature review and conceptual framework addressed in Chapter 2 articulated theories about the material experience (Giaccardi & Karana, 2015) and sustainable practices in a niche level (Rauschmayer et al. 2015) to bridge technology and market in adoption cycles.

Five dimensions are closely related to the four components of the conceptual framework about the material experience for sustainable social practices. For instance, material meaning, assessing sustainable materials, market values, social influence and participation are the outcome in practice of the relations Material, user/people, meaning and skills for sustainability.

Figure 17 shows the relation between the six dimensions and the core of the theory in the Conceptual Framework (figure 10).

These dynamics between the theory and the data gathered in practice are key in the understanding of the niche level and the transition arena. However, for supporting a sustainability transition it is needed to scaling-up the disruptive innovations in the niche level. In order to frame this finding in a MLP, the following chapter will focus on gathering insights from other actors.

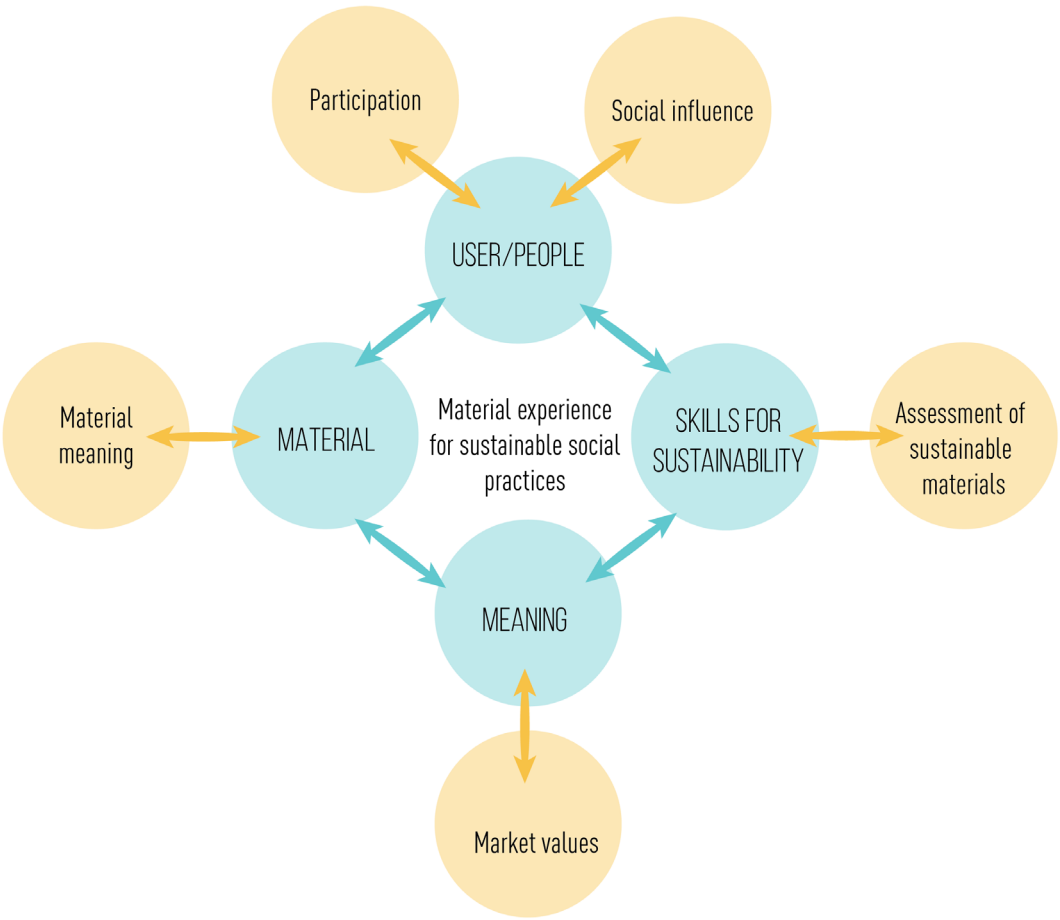


Figure 17. Dimensions in relation to theory

TAKE AWAY

Chapter 4 presented the second stage of the empirical study developed to gain more abstract information about motivations behind of patterns of change, capabilities needed for the transition and vision of users. The methods for collecting and analysing data were meaningful and rich based on the research through design.

Additionally, due to external and extraordinary circumstances, all sessions where held online. It was challenging and perhaps a loss of personal and material interaction. Nevertheless, it was helpful to schedule all sessions in a short period and to engage with people from around the world.

This stage served as a convergent moment where findings helped to validate, complement or further define the results in stage 1.

Six dimensions to describe the user perception of biomaterials transition were found by analysing the data collected in stages 1 and 2. Those are material meaning, assessment of sustainable materials, market values, social influence, participation and tracking the transition.

Finally, in order to support the transition, the following stage will open the discussion and gain insights from other actors involved. The next chapter will address the last stage of the empirical studies, in which validation interviews were conducted with several actors.

CHAPTER 5

Empowering bio

Stage 3. Validation interviews

omaterial niches

This chapter presents the third and last stage of the empirical study in terms of its purpose, methods, analysis of data and results. In the end, it will be presented a discussion section for this chapter and a take away for the following one.

Stage 3 focused on how to empower the biomaterial niches lead by users gaining insights from different actors in the regime and land-scape levels through validation interviews.

Six interviews were held. The results help to frame the previous findings in a multi-level perspective MLP. The findings are merged and summarised in a concept tool for the biomaterial transition.

PURPOSE

Stage 3 was a second divergent moment to collect data. This time from different actors with the goal of validating the findings of the previous stages such as the possible need of others actors to received inputs from users, and to gain insights about the gaps in between fabrication, application and appreciation.

According to the transition theory, another goal of transition research is to support the transition by empowering, managing and mainstreaming disruptive innovations taking place in a niche level as transition arena. Stages 1 and 2 as presented in previous chapters addressed the goals of describing and interpreting the biomaterial transition. To further this findings, the stage 3 sought for opening the conversation to other actors considering that a transition is always happening in a multi-level perspective and several actors need to be articulated to successfully support the innovations.

The statement of developing a tool for the biomaterial transition was a way to engage with participants, and gain insights about their needs.

METHODS

Semi-structured interviews of 60 minutes were held to gather data from other actors as mapped in stage 1. Interviews developed in two moments, the first 30 minutes were held about the research question, and the second part was about the idea of a toolkit for supporting the transition. A guide was designed to follow during the interview as well as schemes as artefacts to hold a conversation about the design and need of a tool.

The sample was defined to reach different actors that interact with users to define the dynamics in the actual regime. Additionally, the involvement with companies and government was an added value from the sample, that's why participants were involved in fields of circular economy, transitions, biomaterials and materials selection. Finally, considering the bottom-up approach of the project and the niches identified in stage 1, domain curator and designers were considering for sampling.

Six interviews were held online, connecting with participants in The Netherlands, Denmark, Brazil and France. Overall, the participants responded positively to the project and were curious to see a tangible tool for the biomaterial transition which can be the aim of further research. Table 10 summarises the sample and main insights gathered during the interview.

Interviewee	***Scope of participant***	***Main insight gained***
Researcher 1	Circular economy strategies	Scope audience for a tool
Researcher 2	Circular economy transitions	Need of users engagement
Material developer 1 in Start-up	Material development (Seaweed)	Need of co-creation with stakeholders during production-consumption chain
Material developer 2 in Start-up	Material development (Mycellium)	People are the motivation and inspiration for development process
Designer inside company	Specification of materials including for products	Small power in material selection (exploration and decision making)
Domain Curator (intermediary)	Giving tools to industry for the transition	Bridge companies and users

Table 10. Participants in interview stage 3

Analysis of the data

In order to analyse the interviews, these were recorded and transcribed. Additionally, the grounded theory method was followed to start developing a theory from the data.

The coding process was initially done in-vivo with Atlas.ti to keep the exact wording of participants, later those codes were grouped in focused codes. A second moment was to classify the focused codes next to the 12 subcategories belonging to 6 dimensions as found in the previous chapter.

Dimension	***Description***	***Subcategory***
Material meaning	Engaging with a new material. Get to know it through sensorial and functional properties	Recognition of material
		Challenge for new bio material
Assessment of sustainable materials	What people need to know to appreciate sustainability in a material, and to assess the bio material cycle source/process/end-of-life	Sustainability knowledge
		Sustainable behaviour
Market values	Importance of the material for the purchase assessment. Mind-set about price & value of product and material	Price and value assessment
Social influence	Within users communication for Self-identification, Social validation and Word of month	Send a message
		Following peers
		Teaching others
Participation	Opportunity for co-creation between actors (Active participation in development/policy)	Engagement in product/material development
Tracking the transition	Recognition of transition and different moments, actual, future and in between	Actual scenario
		Future regime
		Transition

Table 11. Dimensions and subcategories as found in stage 2

RESULTS

The results help to frame the previous findings in context of a multi-level perspective MLP and complement the future vision with perspective of other actors. The findings are merged and summarised in a concept tool for the biomaterial transition.

Main insights about how to support a transition are scoping an audience for giving tools, engage users throughout the fabrication, application, and appreciation, opening opportunities and practical spaces to co-create with stakeholders alongside the production-consumption chain. Additionally, reconsider the material selection process requires to reframe power relation and roles of scientists, engineers, designers, brand manager and users.

For the stakeholders, a main focus is how to reduce the risk of material development. A biomaterial is a radical innovation, for instance, development is highly risky. Previous chapters showed some strategies to reduce the risk, such as material developers launching the products or testing audiences through limited editions. For example, BoltThreads launched the Mylo leather bag in the platform Kickstarter even though it was made in collaboration with Stella McCartney, as well as, Spiber launched the limited edition of the Moon Parka that was made in collaboration with The North Face. This chapter gained insights about the latent need of material developers and designers for involving user in co-creating processes for finding applications for a new material and for material selection in design processes.

There is gap between companies and users and it is bigger when related to material development which can be an opportunity for meaning creation through potentializing sustainable social practices.

CHAPTER DISCUSSION

From the literature review and merging the theories, in essence the way to support the transition is shown in figure 18. It is a process that capitalise the patterns of change growing as disruptive niches in the actual regime to break the lock-in patterns that keep the regime unable to transit to a more sustainable future.

In theory, the idea is simple and straight forward,

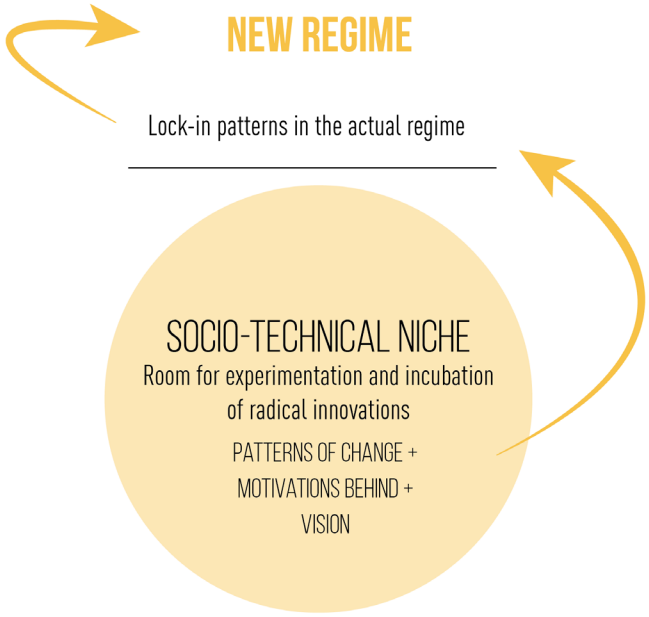


Figure 18. Essence rational for empowering a disruptive niche

however, in practice it is not simple to answer the question of how to successfully empower this niches. To do so, it should be done a process of several disruptive interventions, to assess the changes over time. In article from Loorbach et al. (2020) the extent to which an emergent innovation is transformative, can only be assessed as they are interacting with contexts in 'transformations in the making'.

Transformative innovations are driven by actors across market, state and community logics and connect to others in networks and strategic alliances through which they diffuse. For instance, a following up step would be developing a case or pilot to prove the theory in the making by selecting a niche, defining a concept/ vision and involving several actors.

An interesting niche to test is the fashion Industry. As result of stage 1, the products with more participation and user comments were found in the fashion industry. Additionally, there are more channels available to explore the sustainable offer in this industry. This phenomenon could be due to the relations material, meaning, people and sills. For example. in this industry, the users are normally used to review or comment products, also there is a higher awareness and available data about the negative impact of this industry such as overconsumption, polluting processes, and scare close-loops, so, as consequence, it is where a lot of sustainable initiatives have been focused.

This research proposes the development of a toolbox to support the biomaterial transition. However, a first step for interested stakeholders should be settling an agenda for the user engagement in the material transition based on the material experience for sustainable practices framework.

Concept Tool "a conversation place for co-creating and co-producing a bio-based future"

The tool serves as a catalyst to ignite the user active role and facilitate the transition. The tool has three goals: Align the knowledge and behaviours of different actor, bridge them and guide the transitions.

TAKE AWAY

Chapter 5 presented the last empirical stage diving in the biomaterial transition. The goal of this stage was understanding how disruptive niches lead by users can be supported to transit from one regime to the other by gaining insights from other actors.

Conclusions remark in the constant need of collaboration between stakeholder through out the material journey of fabrication, application and appreciation.

Additionally, others actors in the regime and land-scape level recognised the role of users as active in the increasing importance of civil movements in a land-scape level towards sustainability changes. However, the role of users is still mainly related to their purchase capability which constrict the impact of material experience in social practices.

A tool to support the biomaterial transition in disruptive niches lead by users should be able to connect different actors but also allow users to communicate within them to align knowledge and behaviour towards sustainability. For instance, the tool starts focusing in an individual transition to lead a collective transition.

CHAPTER 6
Integration &

This chapter presents the final conclusions of the thesis, ***The future is bio-based: towards a sustainability transition of biomaterials lead by users.*** Firstly, integrating the different phases and findings presented in previous chapters trough a practical framework for the biomaterial transition. Secondly, discussing their limitations and future pathways for research.

The starting point of the overall thesis is the understanding of strategic design: Instead of finding the right way to solve a problem, strategic design finds what is the right problem. This thesis is developed as graduation project for the master in strategic product design.

& discussion

INTEGRATION

The thesis presented a research project based on literature review and a empirical study with three stages. The research question framing the project is: ***How can the user experience with material be used as a driver in the biomaterial transition?*** This project faced two challenges. One more theoretical, linking the material experience (Giaccardi & Karana, 2015) in shaping sustainable practices (Raushmayer et al. 2015). And one more practical understanding how this relation accelerates or pushes the whole sustainability transition, considering biomaterials as disruptive innovations influenced by processes of diffusion and adoption.

The user experience with materials can accelerate the biomaterial transition through potentialising the role of materials shaping social and cultural practices. On one side, the Material Experience Framework guide the bottom-up approach and on the other side participative processes change dynamics in the production-consumption chain.

Overall, people as consumers, users or citizens have a more active role in shaping markets and society considering consumers as an active meaning creator (Consumer culture theory CCT, 2005). However, this is not wide-spread in the actual regime but appears as innovations in the niche level. Findings of the research showed that people's roles are blurring, so they can equally act as citizens, users, consumers, however in the regime level, the definitions about actors are still polarized in a technological side and a market side, usually regulated for policy makers. In the actual regime users can put pressure not just by making a purchase decision but also by spreading their opinion to put a topic in an agenda or not. In the actual regime, people adapt the industry but in the future one, industry should adapt to people.

The actual regimen is mainly based on a traditional approach to material development in the production-consumption chain. Policy makers appear as regulators and lead the governance of transitions from top to down. Furthermore, finding applications is done mainly by product designers using new materials according to properties descriptions rather than to the user experience.

Framework

This framework is meant to be a user-centred tool for accelerating the biomaterial transition. It can be used for researchers, material developers or policymakers, as a driver for approaching users in the biomaterial transition.

The framework is grounded in the outcomes of the empirical stages and the literature review. Figure 19 shows the framework relating the six dissensions and their evolution over time.

Material meaning, assessment of sustainable materials and market values build the definition of a practice according to the theory and conceptual framework relating material experience and sustainable practices.

Tracking the transitions describe how the behaviour of users evolves on practices over time. For instance, material meaning increase constantly. Assessment of sustainable materials increases strongly at the beginning to empower the disruptive niches but once those are mainstreamed during the transition it continuous more steady. Finally, the market values evolve from price vs value as defined in the actual regime, to redefine the practice by finding new meanings in the user, product and material relation.

CONCLUSIONS

The project followed an inductive reasoning from observation, to patterns, to a proposition answering the research question. Mixed methods created rich data and allowed to gain insights from different perspectives and actors. Research through design allowed articulate the literature and practical knowledge. Several methods proper of the design practice such as booklets and journeys were useful to gain deeper insight from the participants in the studies and to understand better the data.

The project has identified some gaps in the actual regime in terms of aligning users knowledge, behaviour and vision, bridge different actors and guide the transition. Currently, users have different levels of knowledge, behaviour and vision towards sustainability which can be supported towards a material transition.

Overall, there are several communication gaps which decreases the opportunity of new biomaterials to reach their material potential. Additionally, the role of users constricted to their purchase decision reduce the potential of the material experience towards the sustainability transition.

Findings in stages 1 and 2 showed that users seek for a specific combination of process an material attributes in the shape of a product rather than for a certain material, as suggested for the theory (Barati & Karana 2019, Karana & Hekkert 2010). This can be capitalise from the material experience literature to define meanings for bio-based products. On the other hand, users as innovators and early adopters give input for application and initially solve the gap of communication, however, still, there is little interaction between material developers and users or more dynamics in the diffusion and adoption processes. Besides that, comments were found mainly in channels lead by people to people (YouTube, Reddit) this can be further capitalised for supporting the transitions as found in Stage 3.

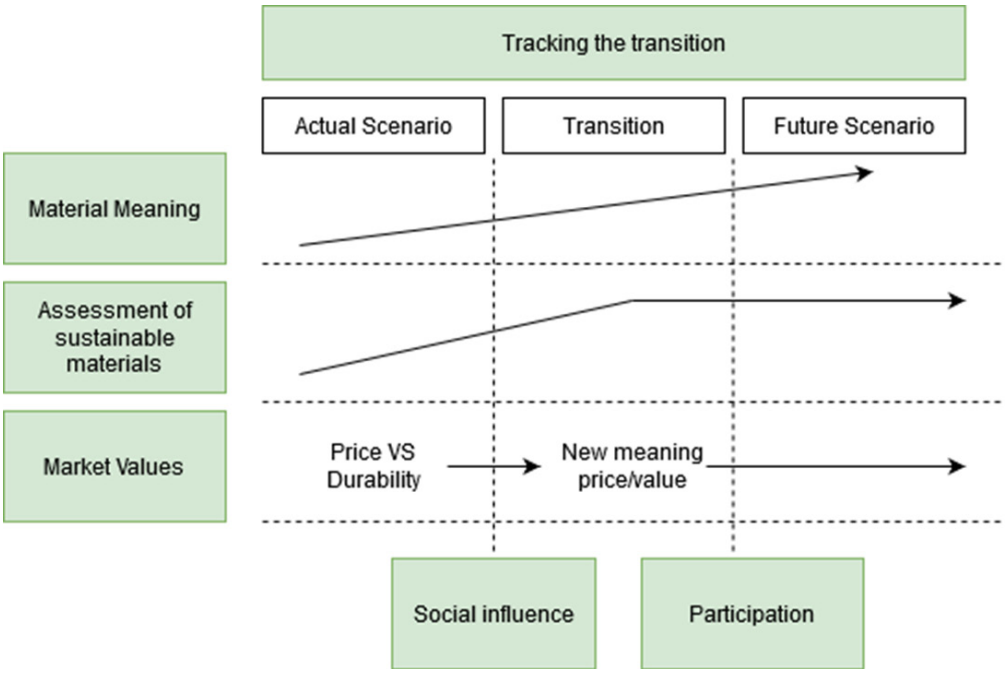


Figure 19. Framework of user-centred approach in the biomaterial transition

DISCUSSION

To answer the research question ***How can the user experience with material be used as a driver in the biomaterial transition?*** This project propose to capitalize on the social life of material artefacts (Giaccardi & Karana, 2015) to shape sustainable practices in the niche level to empower disruptive niches and reach biomaterial transition from the users towards a sustainability transition. This implies finding new dynamics in the production-consumption chain related to materials by bringing actors in fabrication, application and appreciation and redefining their roles.

The biomaterial transition should focus equally on the material development and in the creation of new patters in the society. A biomaterial development does not lead strictly to a more sustainable behaviour, for instance people over-consume, brands use branding and marketing to sell and expand their portfolio, there is no clarity about the end-of-life of new materials or clear assessment of their impact in nature and the environment. Focus on material helps to shape the sustainability transition. It is a societal learning involving vision, development and networking.

Incremental innovation in sustainable transitions tends to lock-in the regime, instead radical innovations in a bottom-up approach destabilise it.

A further consideration in biomaterial transitions lead by user is to adapt to the context in the land-scape to make decision about disruptive niches and set a common vision. For example, Europe traditionally has manage sustainability in top-down approach led by European projects such as Horizons 2020. On the other side, Latin America traditionally has a more bottom-up approach because there is a common distrust for institutions. Such differences can change the set-up for supporting a transition, however, in general, people gain more relevance in the land-scape and civil movements are gaining power over institutions.

People more than buyers, create movement, Köhler et al., (2019) present the role of civil society, culture and social movements in transitions. “Civil society and social movements affect industrial transitions by building support for transition policies and by providing protective spaces for innovation, but they also can have more pervasive and less obvious effects on broader cultural values and beliefs”. The research showed some focuses and roles actually signed as patters of change during the stage one, and can be potentialised to gain relevance for the transition (Hölscher et al., 2018).

Finally, a biomaterial transition lead by the material experience of users in sustainable social practices requires deepening in the role of design allowing involving people in user centred approaches and reconsidering power dynamics. For example, participation in a design process does not depend necessarily on the set of methods used or skills transferred, but on the actual redistribution of power happening in the design decision process (Sangiorgi, 2011, p.35)

Limitations

Overall, the empirical study (online review, generative sessions and validation interviews) sought for adding a practical approach to the finding in the literature review. The stages were highly exploratory and iterative like going to the theory into the wild. Further research can carry more studies and methods to validate and deepening the findings of the present research. For instance, considering power dynamics, politics and governance that in reality allow a disruptive niche to grow and challenge the existing regime.

Furthermore, the empirical study was framed in a research through design approached leading to rich data, however, the findings might be constricted to the set-up of the actual graduation project considering time and manageable groups of people for one facilitator/researcher.

Further research

Some insights gained during the project go beyond the research question. Further research can reach other gaps and actors. E.g. material driven businesses. Some gaps are described following:

The available literature about the material transition is scare. Further research with a strategic aim can apply research through design RtD to build on the material transition field until developing theory as suggested by Zimmerman et al. (2010). Theory for design is developed with the intention of improving the practice of design and further research might build on the current material driven design MMD with a focus on sustainability transitions. Currently, MDD is used mainly in a concept product level and not as a regular practice.

By implementing transition theory in action research processes, new insights emerge on individual and societal levels. Those could be implemented and reflected further in research with more practical focus leading the development of a tool.

A big question that still remains after the discussion, is how to assess the state of a transition and what is its pace. Theory does not explore how to measure the development or success of empowering disruptive niches.

Additionally, users are gaining importance for material development by giving feedback to producers and insights to designers. However, they still do not have a role in policies, but domain curators appeared in the land-scape level, as well as networks creating ecosystems bridging users, developers and overall, connecting technology and marketing sides. Further research can focus on how to support these domain curators and networks towards the transition.

TAKE AWAY

This chapter presented the main outcomes, conlusions of the project.

The future is bio-based: towards a sustainability transition of biomaterials lead by users is a master thesis based on the vision of A bio-based future where biomaterials are part of everyday life, and the transition needed in socio-technical systems by cutting non-renewable materials and redefining cultural and behavioural dynamics in the production-consumption value chain.

With a focus on user experience, the research was aimed to tackle a gap between materials, diffusion of innovations, and sustainability transitions theories by finding how the user experience with material can fasten the biomaterial transition.

The project adopted a research trough design approach, articulating a literature review and a empirical study with three stages (online review, generative sessions and validation interviews). Several methods proper of the design practice such as booklets and journeys were useful to gain deeper insights from the participants in the studies and to understand better the data.

Results broaden the perception of biomaterials as disruptive innovations. Thus, deepening in their role in shaping social practices redefine the material culture towards a sustainability transition.

References

Appels, F. V. W., Camere, S., Montalti, M., Karana, E., Jansen, K. M. B., Dijksterhuis, J., Krijgsheld, P., & Wösten, H. A. B. (2019). Fabrication factors influencing mechanical, moisture- and water-related properties of mycelium-based composites. Materials & Design, 161, 64–71. https://doi.org/10.1016/j.matdes.2018.11.027

Barati, B., & Karana, E. (2019). Affordances as materials potential: What design can do for materials development. International Journal of Design, 13(3), 105-123

Camere, S., & Karana, E. (2018). Fabricating materials from living organisms: An emerging design practice. Journal of Cleaner Production, 186, 570–584. https://doi.org/10.1016/j.jclepro.2018.03.081

Camere, S., Karana, E. (2018b). Experiential characterization of materials: Toward a toolkit, In the Proceedings of the International Conference on Design Research Society (DRS), Limmerick.

Cramer, J. (2017). The Raw Materials Transition in the Amsterdam Metropolitan Area: Added Value for the Economy, Well-Being, and the Environment. Environment: Science and Policy for Sustainable Development, 59(3), 14–21. https://doi.org/10.1080/00139157.2017.1301167

Cramer, J. M. (2020). Practice-based model for implementing circular economy: The case of the Amsterdam Metropolitan Area. Journal of Cleaner Production, 255, 120255. https://doi.org/10.1016/j.jclepro.2020.120255

Dahl, D. W., & Hoeffler, S. (2004). Visualizing the Self: Exploring the Potential Benefits and Drawbacks for New Product Evaluation. Journal of Product Innovation Management, 21(4), 259–267. https://doi.org/10.1111/j.0737-6782.2004.00077.x

Danneels, E., & Kleinschmidtb, E. J. (2001). Product innovativeness from the firm's perspective: Its dimensions and their relation with project selection and performance. Journal of Product Innovation Management, 18(6), 357–373. https://doi.org/10.1111/1540-5885.1860357

Eagar, T. W. (1995). Bringing new materials to market. Technology Review; ABI/INFORM Global 98, 2.
Farla, J., Markard, J., Raven, R., & Coenen, L. (2012).

Sustainability transitions in the making: A closer look at actors, strategies and resources. Technological Forecasting and Social Change, 79(6), 991–998. https://doi.org/10.1016/j.techfore.2012.02.001

Giaccardi, E., & Karana, E. (2015). Foundations of Materials Experience. Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems - CHI '15, 1. https://doi.org/10.1145/2702123.2702337

Gaziulusoy, İ., & Erdoğan Öztekin, E. (2019). Design for Sustainability Transitions: Origins, Attitudes and Future Directions. Sustainability, 11(13), 3601. https://doi.org/10.3390/su11133601

Hende, E. A., & Schoormans, J. P. L. (2012). The Story Is As Good As the Real Thing: Early Customer Input on Product Applications of Radically New Technologies. Journal of Product Innovation Management, 29(4), 655–666. https://doi.org/10.1111/j.1540-5885.2012.00931.x

Hölscher, K., Wittmayer, J. M., & Loorbach, D. (2018). Transition versus transformation: What's the difference? Environmental Innovation and Societal Transitions, 27, 1–3. https://doi.org/10.1016/j.eist.2017.10.007

Jacobs, R. . S., Heuvelman, A., Ben Allouch, S., & Peters, O. (2015). Everyone's a critic: The power of expert and consumer reviews to shape readers' post-viewing motion picture evaluations. Poetics, 52, 91-103. https://doi.org/10.1016/j.poetic.2015.07.002

Karana, E., Blauwhoff, D., Hultink, E-J., & Camere, S. (2018). When the Material Grows: A Case Study on Designing (with) Mycelium-based Materials. International Journal of Design, 12(2), 119-136. http://www.ijdesign.org/index.php/IJDesign/article/view/2918

Karana, E., & Hekkert, P. (2010). User- material-product interrelationships in attributing meanings. International Journal of Design, 4(3), 43-52.

Karana, E., Pedgley, O., & Rognoli, V. (2014). Materials Experience: Fundamentals of Materials and Design (1st ed.). Butterworth-Heinemann. https://doi.org/10.1016/C2012-0-02198-9

Köhler, J., Geels, F. W., Kern, F., Markard, J., Onsongo, E., Wieczorek, A., Alkemade, F., Avelino, F., Bergek, A., Boons, F., Fünfschilling, L., Hess, D., Holtz, G., Hyysalo, S., Jenkins, K., Kivimaa, P., Martiskainen, M., McMeekin, A., Mühlemeier, M. S., ... Wells, P. (2019).

An agenda for sustainability transitions research: State of the art and future directions. Environmental Innovation and Societal Transitions, 31, 1–32. https://doi.org/10.1016/j.eist.2019.01.004

Kozinets, R. V. (2015). Netnography. The International Encyclopedia of Digital Communication and Society, 1–8. https://doi.org/10.1002/9781118767771.wbiedcs067

Loorbach, D., Frantzeskaki, N., & Avelino, F. (2017). Sustainability Transitions Research: Transforming Science and Practice for Societal Change. Annual Review of Environment and Resources, 42(1), 599–626. https://doi.org/10.1146/annurev-environ-102014-021340

Loorbach, D., Wittmayer, J., Avelino, F., von Wirth, T., & Frantzeskaki, N. (2020). Transformative innovation and translocal diffusion. Environmental Innovation and Societal Transitions, 35, 251–260. https://doi.org/10.1016/j.eist.2020.01.009

Out Of Tune, living with invisibles. (2019). Retrieved from https://www.materialincubator.com/out-of-tune-living-with-invisibles

Pariser, E. (2012). The Filter Bubble: How the New Personalized Web Is Changing What We Read and How We Think(Reprint ed.). Penguin Books.

Moreau, C. P., Lehmann, D. R., & Markman, A. B. (2001). Entrenched Knowledge Structures and Consumer Response to New Products. Journal of Marketing Research, 38(1), 14–29. https://doi.org/10.1509/jmkr.38.1.14.18836

Rauschmayer, F., Bauler, T., & Schäpke, N. (2015). Towards a thick understanding of sustainability transitions — Linking transition management, capabilities and social practices. Ecological Economics, 109, 211–221. https://doi.org/10.1016/j.ecolecon.2014.11.018

Rogers, E. M. (2003). Diffusion of Innovations, 5th Edition (5th ed.). Free Press.

Rognoli, V., Bianchini, M., Maffei, S., & Karana, E. (2015b). DIY materials. Materials & Design, 86, 692–702. https://doi.org/10.1016/j.matdes.2015.07.020

Rotmans, J., Kemp, R., & van Asselt, M. (2001). More evolution than revolution: transition management in public policy. Foresight, 3(1), 15–31. https://doi.org/10.1108/14636680110803003

Sanders, L., & Stappers, P. J. (2013). Convivial Toolbox: Generative Research for the Front End of Design (Illustrated ed.). Laurence King Publishing.
Sauerwein, M., Karana, E., & Rognoli, V. (2017). Revived Beauty: Research into Aesthetic Appreciation of Materials to Valorise Materials from Waste. Sustainability, 9(4), 529. https://doi.org/10.3390/su9040529

Sengers, F., Wieczorek, A. J., & Raven, R. (2019). Experimenting for sustainability transitions: A systematic literature review. Technological Forecasting and Social Change, 145, 153–164. https://doi.org/10.1016/j.techfore.2016.08.031

Spencer, L., Ritchie, J., Ormoston, R., O'Connor, W & Bardman, M. (2014). Analysis: principles and processes. In Ritchie, J., Lewis, C., McNaughton N. & Ormoston, R. (eds). Qualitative research practice: A guide for social science students and researches. (2dn ed, pp. 269-293). London: SAGE

STNR (2017). A research agenda for the Sustainability Transitions Research Network. https://transitionsnetwork.org/wp-content/uploads/2018/01/STRN_Research_Agenda_2017.pdf

Urmetzer, S., Lask, J., Vargas-Carpintero, R., & Pyka, A. (2020). Learning to change: Transformative knowledge for building a sustainable bioeconomy. Ecological Economics, 167, 106435. https://doi.org/10.1016/j.ecolecon.2019.106435

Upham, P., Bögel, P., & Dütschke, E. (2020). Thinking about individual actor-level perspectives in sociotechnical transitions: A comment on the transitions research agenda. Environmental Innovation and Societal Transitions, 34, 341–343. https://doi.org/10.1016/j.eist.2019.10.005

Vargo, S. L., Akaka, M. A., & Wieland, H. (2020). Rethinking the process of diffusion in innovation: A service-ecosystems and institutional perspective. Journal of Business Research, 116, 526–534. https://doi.org/10.1016/j.jbusres.2020.01.038

Verplanken, Bas (2018). Promoting sustainability: Towards a segmentation model of individual and household behaviour and behaviour change. Sustainable Development, 26, 193-205

Zimmerman, J., Stolterman, E., & Forlizzi, J. (2010).

An analysis and critique of Research through Design. Proceedings of the 8th ACM Conference on Designing Interactive Systems - DIS '10, 310–319. https://doi.org/10.1145/1858171.1858228

ACKNOWLEDGMENTS

Thanks to all people involved that helped me to overcome this extraordinary time. Specially my friends and family.

Thanks to all the participants for their willingness and insightful comments for a shared vision.

Thanks to my supervisors to give me freedom to shape the topic and explore different methods and approaches.

It was challenging to develop stages 2 and 3 completely online, missing social interaction and the possibility of users to interact with materials or products. However, people are now more used to video calls and meetings, so, it was easier to schedule all the activities and their response was quite active.

The new online world allowed me to connect with people in different countries such as Colombia, Brazil, Indonesia, Belgium, France, Italy and The Netherlands despite distance and time. This gives the feeling of change and hopefully this change will be for the best, supporting the sustainability transition.

"A journey of a thousand miles begins with a single step" Lao Tzu