The Materials Generation

The emerging experience of DIY-Materials

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For my wife, my son, my mother, my brother my father and my sister.

We humans must always take responsibility for our actions. We only have one life and one planet. We should live both wisely.

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Abstract

English

The DIY movement is expanding beyond products to include the materials from which the products are made; namely, DIY-Materials. Designers around the globe are engaging in different experimental journeys encircling the materials development field before developing their projects. The design process includes the phase in which the material is developed, and this phase influences the whole creative pathway. Self-made material sources are providing designers with a unique tool to develop new languages and new products with original and fresh materials experiences. As more designers take this path of materials development, which can be defined as design driven, a proper study around the phenomenon needs to be carried out. This dissertation presents a series of studies conducted to understand the DIY-Materials phenomenon as one of the emerging materials experiences in the field of design.
The research was called "Materials Generation" on purpose as it takes advantage of the double meaning of the expression. It refers to the new generation of designers who are aware of the possibilities that emerge when a project starts with the generation of material.

This research aims to describe and define the phenomenon of self-production of materials. It is grounded in the development of a series of codes and categories inside a system of rules to organize information around this particular class of materials. The proposed theory is composed of a language that allows seeing everything that surrounds from an alternative perspective. Living in a world of matter, everything we can touch, smell, see, hear and taste build up our lives. After the industrial revolution, societies were shaped in the way the technological advancements evolved. However, there is an alternative point of view. There is another way to see the world. The DIY-Materials theory is an attempt to produce a system of rules and conventions to categorize the different sources available on the planet and the technologies

to transform them. Different from traditional sciences and economic approaches, where extraction of natural resources, mass production and trade of goods around the globe are the driving force, the self-production of materials offers a series of alternative principles and methodologies able to guide a more autonomous and independent way to produce things. It helps to relief from the weight and responsibility to depend on the current dominant world economy. Promotes an alternative idea of smart use of resources, considering resource even elements that before weren`t even considered. This research proposes a sustainable and circular perspective which can promote new social innovations starting from the materials. Within, it is possible to view and understand the opportunities DIY-Materials offer when considered as a possible practice in the design domain.

In order to distribute the different subjects coherently, The herein presented research has been structured by formulating the research questions and hypotheses, the qualitative methods and strategies to conduct different tests, and how the different elements are attempting to define this phenomenon together clearly.

The goal of this research is to provide more insights into the phenomenon of DIY-Materials, by creating a theoretical framework for reference with a series of steps to develop a material form an experimental design approach.

The dissertation consists of four main parts.
Part one: The first two chapters are the introductory part. They provide an introduction and overview of the entire research, focusing the attention on the organization and development of the research.

Part two is the theoretical background: inside chapter three there is a summary of the different theoretical elements considered during the research. Made with a brief historical review of the materials for the design domain, moves to the theoretical foundations of the DIY and the DIY practices. The chapter ends with a focus on sustainability-related theories. The three topics construct the three macro areas of research.

Part three presents the different studies conducted during the Ph.D. research: The initial three chapters of this part present the exploratory

studies conducted to understand the DIY-Materials phenomenon better. This part is composed of three exploratory studies: cases collection and categorization (Chapter Four), evaluation (Chapter Five) and aesthetical evaluation of DIY-Materials (Chapter Six).
The latter two chapters present the test studies conducted to validate hypotheses and gather insights for the DIY-Materials theory building: DIY-Materials development level I (Chapter Seven) and DIY-Materials development level II (Chapter Eight).

Part four is composed of the different outcomes of the research as well as the discussion and general conclusions of the research as an original contribution to the field of study. Chapter Nine presents the different outputs of the different investigations, proposes a roadmap for the efficient development of a DIY-Material with a test study and presents two strategies for the dissemination of the DIY-Materials theory. Finally, Chapter Ten poses a discussion on the conducted research highlighting possible opportunities for the future of this phenomenon together with a report of activities, dissemination work and credits to all designers who participated in the research.

Anticipating some of the personal reflections emerged at the end of this Ph.D., is possible to say that designers have not only the possibilities to generate materials, but also have the tools to produce them creating meaningful experiences. The different studies produced during this dissertation in addition to the material samples and physical results become essential elements enriching the DIY-Materials Theory. The results of this research will spark curiosity and hopefully also interest and passion around the materials development, highlighting the possibilities design have to offer to the materials science and engineering domain.

Abstract

Italiano

Il movimento DIY è tornato a crescere e, nel contesto del design, oltre agli oggetti coinvolge oggi anche i materiali con cui realizzare gli oggetti stessi; vale a dire i materiali autoprodotti, o DIY-Materials. A livello internazionale i designer hanno intrapreso un'attività di sperimentazione diretta allo sviluppo dei materiali prima ancora di cominciare il processo progettuale dell'oggetto, anzi si potrebbe dire che il processo progettuale include la fase di sviluppo del materiale e in particolare questa fase influenza poi tutto il percorso creativo.
Il processo di autoproduzione dei materiali e dei processi è un'occasione unica per i designer che vogliono sviluppare nuovi linguaggi e nuove identità, dando al risultato finale un'esperienza materica originale e autentica. Ormai gli esempi di questo nuovo approccio ai materiali, che è possibile definire come design driven, sono molti, si è ritenuto necessario condurre uno studio adeguato sul fenomeno che è stato appunto chiamato DIY-Materials. La ricerca qui presentata illustra una serie di ragionamenti e studi finalizzati alla comprensione di questo fenomeno considerato come una delle esperienze materiche emergenti nel campo del design.
La ricerca è stata chiamata "Materials Generation" e volutamente si approfitta del doppio senso di questa espressione che si riferisce alla nuova generazione di designer attenti al progetto dei materiali e comunica inoltre il processo generativo del materiale stesso che è alla base dell'autoproduzione.
Il fine principale della tesi è quello di descrivere e definire il fenomeno dell'autoproduzione dei materiali e per farlo sono state create delle categorie specifiche e un sistema di regole per organizzare le informazioni attorno a questa che si delinea come una classe particolare di materiali per il design. La teoria proposta consente di vedere i materiali da una prospettiva alternativa e ha la presunzione di invitare coloro che ancora non hanno intrapreso questo tipo di processo creativo e progettuale a cominciare a ragionare sui materiali in una logica

di autoproduzione.
Vivendo in un mondo dove tutto è materia, tutto ciò che è possibile toccare, odorare, vedere, ascoltare e gustare, influenza il comportamento e la vita stessa. Dopo la Rivoluzione Industriale, le società sono state modellate a ritmo dell'evoluzione dei progressi tecnologici e questo sembra essere ancora oggi il paradigma imperante. In questo contesto, la teoria sui DIY-Materials che vieni qui proposta, vuole porsi come un punto di vista alternativo, un modo anticonformista di vedere il mondo dei materiali e delle tecnologie. Diversamente dall'approccio scientifico tradizionale fortemente influenzato dalle forze economiche, dove l'estrazione delle risorse naturali, la produzione di massa e il commercio internazionale di merci ne costituiscono la forza trainante, la proposta dell'auto generazione dei materiali può essere vista come un insieme di principi e metodologie alternative in grado di guidare in un modo più autonomo e indipendente la produzione di cose. Ci si libera in un certo senso dal peso e dalla responsabilità di dipendere dalle dominanti economie mondiali ma anzi si promuove un'idea alternativa dell'uso intelligente delle risorse, considerando risorsa anche ciò che fino ad oggi non lo era. Ci si cala in una prospettiva sostenibile e circolare che possa promuovere meccanismi di innovazione sociale, comprendendo le opportunità offerte dai DIY-Materials e considerandola come una pratica possibile nell'ambito del design.

Per distribuire gli argomenti in modo chiaro, la ricerca è stata strutturata formulando in primo luogo le domande e le ipotesi di ricerca, i metodi qualitativi e le strategie per condurre i diversi studi e i vari elementi che tentano di definire il fenomeno. L'obiettivo di questa ricerca è quello di fornire maggiori informazioni sul fenomeno dei DIY-Materials, creando un quadro teorico di riferimento con una serie di passaggi finalizzati allo sviluppo materico con un approccio di progettazione sperimentale.
La tesi è composta da quattro parti.
Prima parte: i primi due capitoli costituiscono la parte introduttiva, fornendo una panoramica dell'intera ricerca e concentrando l'attenzione sull'organizzazione e sullo sviluppo dell'intero lavoro.

Seconda parte: è il background composto da una sintesi dei molteplici concetti teorici presi in considerazione durante lo svolgimento della ricerca. Partendo da una breve revisione storica dei materiali per il design, si passa ai fondamenti teorici delle pratiche del do-it-yourself.

Si conclude con un focus sulle teorie relative alla sostenibilità. Questi tre argomenti costruiscono le tre macro aree di ricerca.

Terza parte: presenta i diversi studi esplorativi condotti per comprendere meglio il fenomeno dei materiali DIY. Sono stati eseguiti tre studi esplorativi: 1_raccolta e categorizzazione dei casi (capitolo quattro), 2_valutazione (capitolo cinque) e 3_valutazione estetica dei materiali DIY (capitolo sesto).
Successivamente vengono presentati gli studi di prova condotti per convalidare le ipotesi e raccogliere gli approfondimenti per la costruzione della teoria dei DIY-Materials: livello di sviluppo dei materiali autoprodotti I (capitolo sette) e livello di sviluppo dei materiali autoprodotti II (capitolo otto).

Quarta parte: raccoglie i vari risultati della ricerca, le discussioni e dalle conclusioni generali sottolineandone il contributo originale al campo di studio. Il capitolo nove propone i risultati delle varie indagini e propone una tabella di marcia per lo sviluppo efficiente di un materiale autoprodotto, presentando inoltre due strategie per la diffusione della teoria su questa classe emergente di materiali per il design. Infine, il Capitolo 10 suggerisce una discussione sulla ricerca condotta evidenziandone le possibili opportunità per il futuro di questo fenomeno.

Anticipando alcune delle riflessioni personali emerse alla fine della mia ricerca di PhD, posso dire che i designer non hanno solo la possibilità di progettare i materiali, ma hanno anche gli strumenti per generarli generando nuove identità ed esperienze significative. Con gli studi prodotti e i campioni di materiali e i risultati concreti di questa ricerca ho cercato di definire il fenomeno e delinearne e arricchirne la teoria. Sono sicuro nel dire che i risultati di questa ricerca incuriosiranno i più e spero suscitino l'interesse e la passione dei progetti, mettendo in luce contemporaneamente quello che il design ha da offrire alla scienza e all'ingegneria dei materiali.

Chapter One

Introductory Subjects

Nowadays, the products surrounding us derive primarily from industrial materials, i.e., materials that are developed in order to answer mass production requirements and constraints. And it does not look like it will be changing any time soon. However, it is observable that over the last few years, another interesting phenomenon has emerged, bringing a new dimension to the relationship amongst designers, technologies, production processes, and materials. It is known as DIY-Materials (Do-It-Yourself Materials) to highlight the principal characteristic of this "new class" of materials, which are conceived by the designer and their development is characterized by a tinkering approach and a self-production process (Rognoli et al., 2015). This new approach to materials development is enhanced by the renaissance of craftsmanship, by the democratization of the technologies and all the practices combining making, crafting and personal fabrication (Bettiol & Micelli, 2014; Tanenbaum et al., 2013).
The DIY movement expands beyond final products and includes the materials which make the products (Brownell, 2015). From a previous definition, it is possible to understand this new class of materials as "created through individual or collective self-production practices, often by techniques and processes of the designer's invention. They can be entirely new materials, modified, or further developed versions of existing materials" (Rognoli et al., 2015). This definition is still valid and correct and is the starting point of this doctoral research, which aims to provide a more comprehensive framework to understand this remarkable phenomenon.

1.1. The DIY-Materials Phenomenon

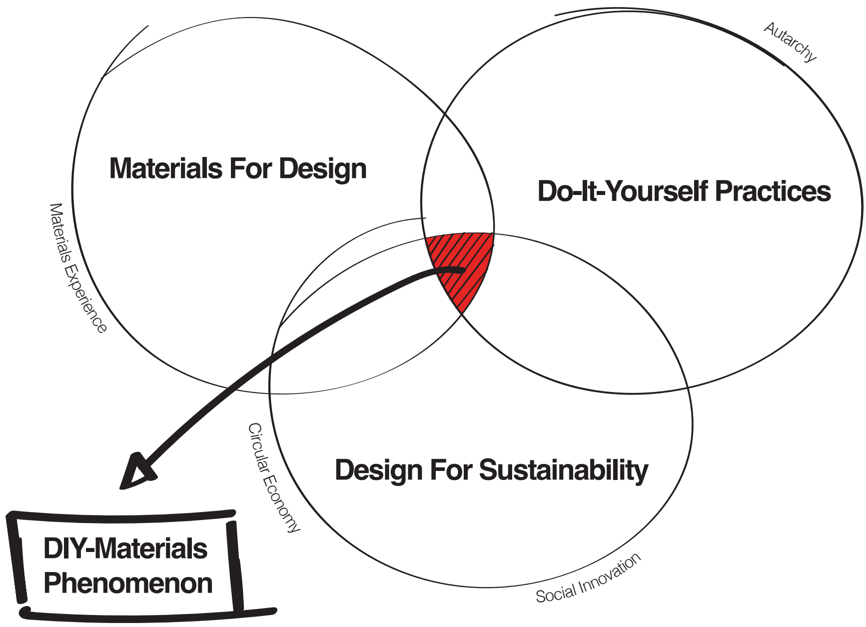
DIY practices are taking on different fields of knowledge and expertise. Among these, the materials for design domain is increasingly witnessing designers making use of these practices. In our opinion, it happened for several reasons including the interests related to more

sustainable futures and attention to the social innovation perspective. Furthermore, the designers who have embarked on a path of development and self-production of materials, they also wanted to demonstrate their dissatisfaction with the monotonous uniformity of the industrial material landscape, and therefore they tried to generate original material experiences, even transforming themselves into real activists (Ribul, 2013) against the mass-production system. It seems that designers enjoy regaining control of the ideation and production processes, getting their hands dirty by experimenting with colors, textures, consistencies, mixing various ingredients and having fun looking for alternative and unconventional sources as raw materials. DIY-Materials practices promote knowing in action (Schön, 1983), i.e., experiential knowledge with and through materials. The outcome of this process is often a self-produced material as a result of making things by hand, but also by thinking through the hand-manipulated materials (Nimkulrat, 2012). Thus, the process of making materials by hand can be identified as a way of thinking intellectually (Sennett, 2008) and a way of tinker manually (Parisi et al., 2017). Designers, furthermore, require a dynamic process of learning and understanding through material experience (Gray & Burnett, 2009, p. 51) for designing with materials (Karana et al., 2015).
The study began by asking: what is the origin of DIY Materials? Moreover, what can serve as a material source for their development? As there exists only a limited amount of literature in the emerging field and several types of research being applied on the subject around the globe, it was crucial to propose a more in-depth categorization and theory structure. There is a high chance for this phenomenon to continue to grow and become established, creating balance within the materials domain.

1.2. Theoretical requirements

The theoretical background of this study is composed of three macro-areas of research: materials for design theories, DIY practices, and design for sustainability (Figure 1.1). Through these three macro-areas, there is an opportunity to connect other significant theoretic contribution like the concepts of materials experience, the autarchic approach to materials and technologies (De Almeida Meroz, 2014; Bosoni & De Giorgi, 1983), and the circular economy principles and social innovation research.
The principal aim of this dissertation is to illustrate the possible paths

Figure 1.1
The three macro areas of research and where the DIY-Materials phenomenon can be better understood.



for these areas to encounter. The study underlines the three agendas and topics coherently but does not intend to force the merge of the three topics as a whim or just for the sake it. Instead, it highlights the opportunities occurring when these topics encounter one another.

1.3. Motivations

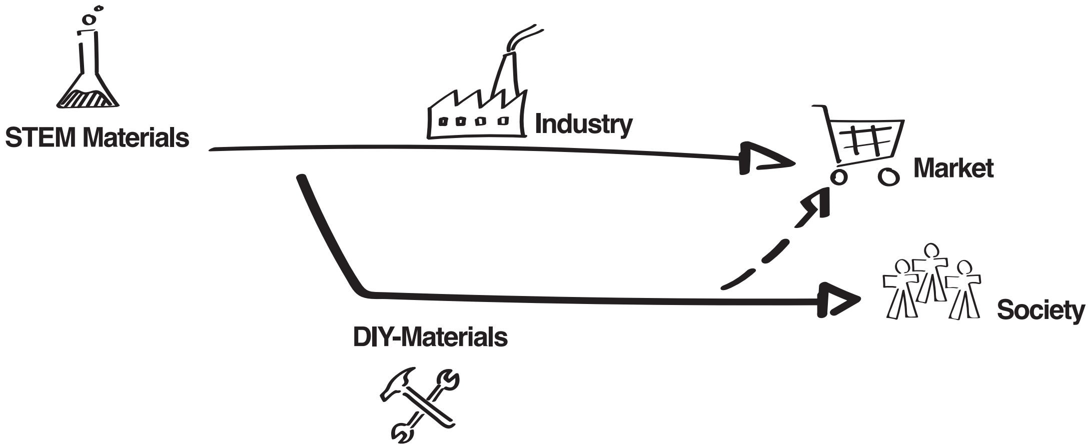
The doctoral research concentrates on the connections between the three macro areas of research, their topics and opportunities for the future of materials for design, keeping the following considerations in view:

a) The eternal relationship between people and things (material culture studies[1]);
b) The ways in which human beings relate to their environment (ecological anthropology[1]); and
c) The issues of maintenance of our society and the planet (sustainability and social innovation).

1. Material Culture & Ecological Anthropology are defined by Ingold as recently opposite schools of thought. However, in this dissertation there are several moments in which both fields meet. Ingold, T. (2012). Toward an Ecology of Materials. Annual Review of Anthropology, 2012. 41: 427–42.

Societies need a driver which allows social innovation for the material culture. There is, and there always will be a technological innovation that is driven by the development of science and technology continuously investigating intelligence in materials (e.g., nanotechnology, memory, self-transformation). Nevertheless, materials in science

always have the problem of accessibility, which means neither designers nor communities can gain quickly access to those materials that are developed in the lab. Unfortunately, some decades will have to pass before it will be possible to buy them in standard formats. This study focuses on another possible path for materials development and accessibility (Figure 1.2).
Humans have to find alternative ways not only to produce but to use



and dispose off materials. DIY practices are taking on materials now. It is a growing trend that needs an in-depth study and outcome; DIY was born as a social movement and, therefore, it is expected to lead to social change.

Figure 1.2
DIY-Materials as an alternative to traditional materials developed by science.

1.4. The research questions

The research questions, sub-questions and the hypotheses guided the different stages of the research. One main question remained instrumental in guiding the process.

Research Question (RQ1)
What causes the DIY-Materials Phenomenon?

As it is a broad question that can be interpreted in many ways and can lead to many different results, the formulation of three sub-questions provide a more detailed focus:

(a) **Who** decides to embark in a DIY-Materials development?
(b) **Why** do people decide to do their materials?
(c) **What** are the differences between DIY-Materials and other materials?

This research question and its sub-questions helped to organize a research method and with it, a systematic collection of cases and best practices of this phenomenon as reported in **chapters four to six** of the dissertation. The answer to the main research question is visible in the conclusions on **chapters four, five and six**. **Chapter Four** expands on the question of who decides to embark on a DIY-Materials development, while **chapter Five** focus on why people decide to do their materials. **Chapter Six** explores the differences between DIY-Materials and other materials by evaluating them from the aesthetical, expressive-sensorial and experiential aspects above the technical ones.

After the findings obtained by developing a categorization of the different cases, a second research question emerged. It was evident that by determining the causes of the phenomenon and the reasons why people do materials will not provide enough contribution to the field of study. The questions of "what" and "why" needed to be expanded upon. They helped to create a better description, and surely the classification became an essential element for a better comprehension of the phenomenon. Nevertheless, if the phenomenon continues to grow, as it certainly did since the start of the doctoral research to the writing of this chapter, it was essential to explore where it would go. What difference could it make compared with traditional materials developed by STEM (science, technology engineering, and mathematics sciences)?[2]

2. STEM is a term first used by the U.S. federal agencies to call the core sciences in the field of education for funding scientific research. Gonzalez, H., Kuenzi, J. (2012) Science, Technology, Engineering and Mathematics (STEM) Education: A Primer. Congressional Research Service.

On the evidence proved by the initial studies presented in **Chapters Four, Five and Six** of the dissertation, where the essential knowledge on crafts is a determinant for a designer to embark on a materials development, the second research question shaped the rest of the doctoral study.

Research Question (RQ2)
Who can generate a DIY-Material?

Chapter Four explains how many artists, architects, and designers who have developed a material come either from a family of craftsmen, are trained to approach materials through their higher education or are DIY enthusiasts and believe in the open source and maker movements. This insight creates a niche inside the entire design field putting the willingness and capabilities to craft in the first place. All those with no intention to make with their hands will be hypothetically taken out. The answer to the second research questions appears in the conclusions on **chapter four**.

1.5. Research objectives

General Objective

Develop a theoretical framework which allows the practice of DIY-Materials to become available and implemented by a broader design audience.

Specific Objectives

The first objective is to highlight the possibilities that DIY-Materials can provide when considered as a possible practice in the field of design.

The second objective is to find and define a proper set of guidelines that can be utilized by a person who wants to develop a project starting from the material.

Key Words

-DIY-Materials
-Emerging Materials Experiences
-Tinkering with Materials
-Expressive-Sensorial Characterization of Materials
-Experiential Qualities of Materials
-Materials for Design
-Democratization of Materials

1.6. The research hypotheses

Theory building starts with propositions and hypotheses, where relationships among variables emerge. A series of hypotheses were proposed to guide the studies finding information to measure and encounter tendencies towards materials development patterns. According to Kaplan (1964), there are working hypotheses and test hypotheses. Working hypotheses serve to guide and organize the investigation providing something to go on with (p. 88). In this research, the study started with two working hypotheses:

Working Hypothesis (WH1)

The DIY-Materials phenomenon tends to grow. There should be a way to organize it to allow a better understanding.

This hypothesis was verified and is explained in detail in the conclusions on **chapter four**.

Working Hypothesis (WH2)

DIY-Materials emerged from the creative fields of humanities. There should be a gap that traditional STEM materials are unable to fill.

This hypothesis was verified and is explained in the conclusions on **chapters five and six**.

Test hypotheses on the other side come after the investigation is already on track. They are a series of inquiries that may emerge to find the solution to a posed problem.

After being able to understand how in all the cases studied, it was of extreme importance to gain certain degree of familiarity and ability to work with the hands to develop a material, a set of test hypotheses emerged providing further directions for the research. The test hypotheses suggest:

Test Hypothesis (TH1)

There is a relationship between knowing how to craft things and materials development.

This hypothesis was verified and is explained in the conclusions on **chapter seven**.

Having concluded that classifying and organizing materials into different categories and sub-categories provides information about common elements the different cases share, a further observation on similar aesthetic patterns, common motivations and drivers to obtain a better understanding of the phenomenon emerged. A second test hypothesis then suggested:

Test Hypothesis (TH2)
Starting material development from a particular source has an effect on the final material developed.

If any DIY-Materials development starts from a particular kingdom, the designers of the material could carry out a focused research gathering information from similar cases understanding common elements, limitations, and advantages concerning properties and qualities of the material they want to develop as well as the benchmark ones.

This hypothesis was verified and is explained in the conclusions on **chapter seven**.

Finally, another critical conclusion from the exploratory studies revealed that the designers unlike material scientists and engineers had some different motivations. Designers driven by concerns around sustainability and new aesthetics, propose alternatives for what the mass market provides. The third test hypothesis suggests:

Test Hypothesis (TH3)
DIY-Materials were the result of motivations other than what STEM materials commonly have.

The results would be different from what currently exists in the market not regarding performance and capabilities, but regarding what they have to offer to potential users.

This hypothesis was verified and is explained in the conclusions on **chapters Seven and Eight**.

The necessity to perform a fourth study followed the evidence of the potential for a DIY-Material to go further. The fourth research hypothesis allowed to move forward from the tinkering approaches which characterized the third study into a more organized and accurate procedure. The fourth test hypothesis suggests:

Test Hypothesis (TH4)
DIY-Materials can achieve a mature level of qualitative development and it is possible to analyze them with standard methods to reveal qualitative data.

With the combination of data, it is possible to propose paths towards an application.

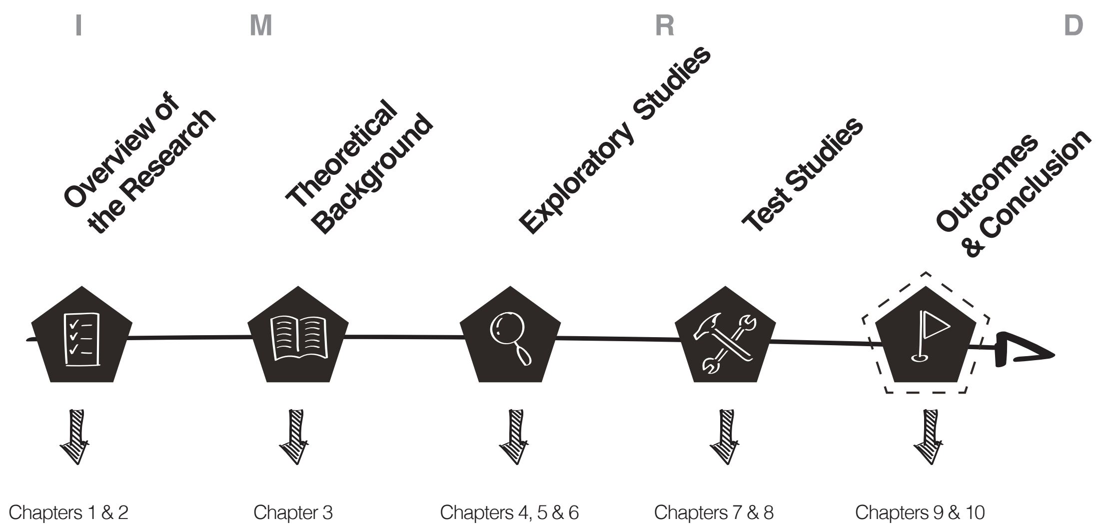
This hypothesis was verified and is explained in the conclusions on **chapter eight**.

To see the relationship between the proposed research questions, the hypotheses and the studies addressing both questions and hypotheses refer to figure 2.8 on **chapter two**.

1.7. The structure of the dissertation

The work consists of four main parts. Figure 1.3 represents the structure of the doctoral dissertation. **Chapters One and Two** are introductory chapters. They provide an introduction and overview of the entire research, focusing the attention on the organization and development of the research. **Chapter Three** introduces different theoretical backgrounds and macro areas of research: materials for design, DIY practices, and sustainability-related theories. **Chapters Four to Six** present the exploratory studies conducted to better understand the DIY-Materials phenomenon. This part is composed of three exploratory studies: cases collection and categorization (Chapter Four), evaluation (Chapter Five) and aesthetical evaluation of DIY-Materials (chapter Six). **Chapters Seven and Eight** present the test studies conducted to validate hypotheses and gather insights for

Figure 1.3
Structure of the Ph.D. Dissertation.



the DIY-Materials theory building. This part is composed of two test studies: DIY-Materials development level I (Chapter Seven) and DIY-Materials development level II (Chapter Eight). **Chapter Nine** presents the different outputs of the different investigations, proposes a roadmap for the efficient development of a DIY-Material with a test study and presents two strategies for the dissemination of the DIY-Materials theory. Finally, **Chapter Ten** poses a discussion on the conducted research highlighting possible opportunities for the future of this phenomenon together with a report of activities, dissemination work and credits to all designers who participated in the research.

The doctoral dissertation is put together to be read continuously or separately according to the reader's interest. Each chapter stands by itself and contains references to connect and allow the search of specific background topics in the other chapters if needed. Regarding the theoretical background chapter (Chapter Three), the whole literature review appears in a summarized form and focuses on the different macro areas of research to better connect with the investigation.

The dissertation contains a series of figures and tables developed to facilitate the reader's understanding of the whole manuscript, support the introduction of concepts and present the research with visual richness. The different cases studied, the various evaluations and some work from the participants become visible in a series of composed boards. By doing so, the focus of the visual aids goes to the materials and not to the product or a specific application. Detailed information about the boards and the database appear in **Chapter Nine**. Appendix with different additional information, some examples of data collection, questionnaires and materials samples, close the work of this dissertation.

Chapter Two

Research Methodology

The whole Ph.D. dissertation is composed of an explorative phase and a test phase. It builds upon several empirical studies aiming to produce a better understanding of the DIY-Materials phenomenon. Support from the different studies comes from the concepts of project-based research (Zimmermann, Forlizzi & Evanson, 2007). When studying a material from a designer's perspective the means by which to do it not only serve to explore the proposed theories physically but also allow for the description of the whole development afterwards. This method is known as design practice. As DIY-Material practices promote knowing in action (Schön, 1983), which is a contemporary way of doing research (Mäkkela, 2007) artists and designers connect themselves with the field of research establishing a practice-led investigation. By looking at the different processes and the work produced through them, it is possible to acquire not only the skills but also the knowledge of the practice. This focus is the central constituent of the DIY-Materials theory.

2.1. Theoretical foundations for the DIY-Materials

Materials knowledge is a crucial element in the field of design. Designers understand physical properties and interact with qualitative attributes of materials all the time when developing the project. Some designers are more aware than others about the role of a material in the artefacts and can create meaningful experiences combining attributes of the product with the attributes of the materials that make it possible. Ezio Manzini provides an important definition to this matter by saying "Matter becomes material when is included in a design project and becomes part of the product" (Manzini, 1986 p.17). This definition can be considered as a pillar in what is known today as materials for design, a section in the materials domain that moves away from the technical and complex understanding of materials of STEM (Science, Technology, Engineering and Mathematics) disciplines and concentrates on the experiential and behavioural interactions between people and the products. In this section of the materials domain appeared in 2009 a concept known as the material experience (Karana,2009) which defines the "experience that people have with and through the materials of a product." (Karana, Pedgley & Rognoli, 2014). This materials experience is rooted in a broader concept known as the product experience. Scholars proposed a framework to highlight how the relationship between user and product is mediated by three levels of experience: sensorial, emotional and meaning (Desmet &Hekkert, 2007). The concept of materials experience take these three levels and add a fourth one: performative level (Giaccardi & Karana, 2015). The four levels affect each other and define the different experiences people obtain when interacting with a material (Figure 2.1). The materials experience concept and framework is quite broad and is observable from different perspectives. One particular side of the materials experience, and the one that is relevant to this research deals with the observation and understanding of three contemporary situations around materials that are impacting the field of design: dynamism, imperfection, and self-production (Figure 2.2).

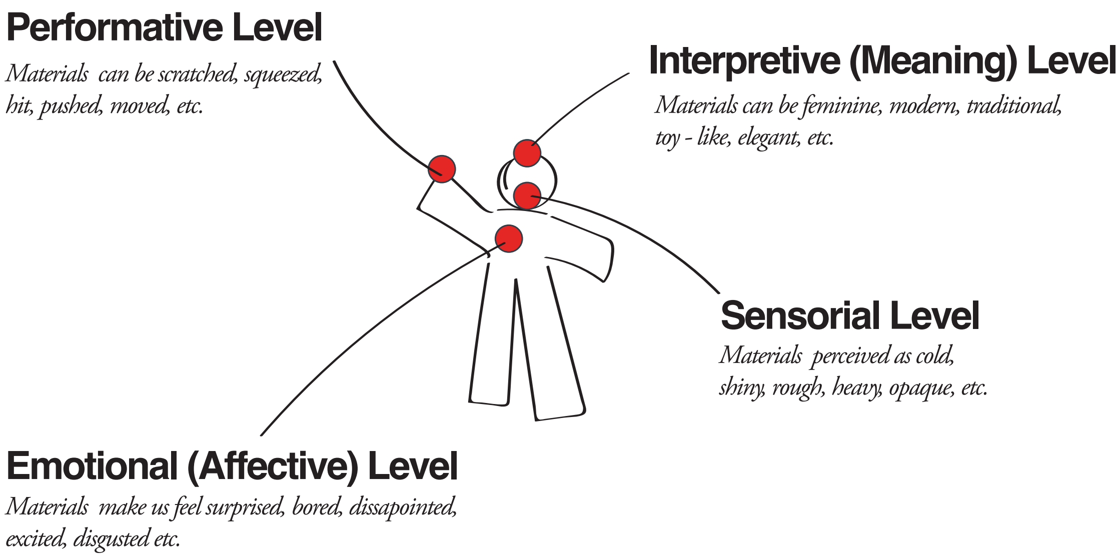


Figure 2.1
Four experiential levels how materials are experienced. Interpretation from the materials experience framework (Giaccardi and karana, 2015).

- *Dynamism*: Materials are dynamic because they change, the change can be slow or fast, reversible or irreversible and is important as time enters into the equation and influences the materials experience.

- *Imperfection*: Today imperfection is a situation people are beginning to accept and understand. When it comes to materials, is possible to observe how smooth and shiny surfaces begin to become imperfect over time. The aesthetics of perfection is gradually giving space to materials capable to provide positive experiences when are carriers of imperfections and are able to tell stories.

For a complete definition of dynamism and imperfection see **chapter seven.**

- *Self-Production*: The last ten years have been the scenario of a material experience characterized by the desire of designers experimenting to achieve new aesthetics and manufacturing processes, intervening not only the product, but the materials.

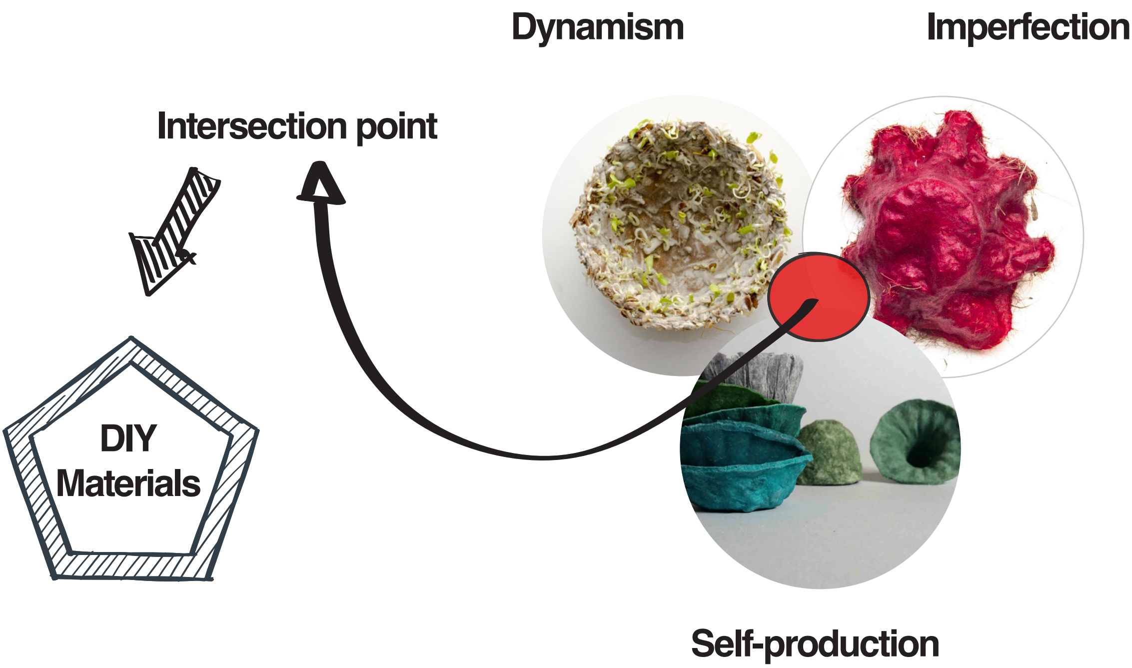


Figure 2.2
Three contemporary materials experiences. Dynamism, Imperfection and Self-production. The three situations intersect.

The above-mentioned, are considered emerging materials experiences and are affecting the recent panorama of design. In the intersection point of the three, it is possible to find a fascinating phenomenon that scholars defined as DIY-Materials and is the core of this dissertation.

2.1.1. DIY-Materials Definition

Rognoli, Bianchini, Maffei & Karana (2015) presented and coined in the materials and design journal, the concept of Do-It-Yourself Materials. This publication put under the spotlight the idea that designers create materials shaped by DIY practices, providing an opportunity to reconsider the features of existing manufacturing processes and industrialized material properties, to develop new, unique experiential qualities. Based on this statement, the initial research question of this investigation seeks for an answer on what causes the DIY-Materials approach to occur. In other words, why designers embark in such quest of producing the material or start a project from the material development?

First definition of DIY-Materials by Rognoli, V., Bianchini, M., Maffei, S., Karana, E., (2015). DIY Materials. Materials and Design, 86(2015), 692-702.

The answer to this question came after the studies of the collected cases presented in **chapter four** and helped in a proposal to extend the current definition of the DIY-Materials.

The current definition of DIY-Materials according to the scholars:

..."we want to illustrate the work of different designers that in the past decade and in this one have decided to take a detour in the path of materials for product design. These designers are becoming a source of inspiration of what we have called Do-It-Yourself Materials. These are materials created through individual or collective self-production practices, often by techniques and processes of the designer's invention. They can be entirely new materials, modified, or further developed versions of existing materials".

The suggested extension to the definition after the pre-study and first study:

"DIY-Materials can be recognized from other materials as they emerge as a transformation of an unconventional source (e.g., grown vegetables, animal constituents, commodity minerals, recuperated waste or a mutation of a common material through an open source technology). The designer is driven regularly by a particular goal (e.g., a way to tackle a wicked problem, give a particular statement or go beyond the industrial mass customized solutions), which can be achieved thanks to the support of a source of inspiration (e.g. a sense of aesthetics, a materials experience vision or the way somebody else do or used to do something). To develop those materials, the designers have control of any technology that can aid in the process and are keen to craft the development itself."

This extension has the value to differentiate this type of materials from the ones produced by the STEM fields, as it explains the unique conditions which enable a DIY-Materials development briefly.

2.2. Research strategies

As mentioned in the first chapter, there is an opportunity to connect Materials Experiences research, Do-it-Yourself practices and autarchic processes research with Sustainability issues related to circular economy principles and social innovation research. These three topics became the three macro areas, and the intersection between them guided the investigation throughout the doctoral studies (Fig 1.1 on page 20).

To connect the three macro areas of research and derive an original and well-funded theory, a selection of two strategies for the first part and five strategies for the second part of the study improved as a crucial element (Figure 2.3).

The first part addresses the understanding of the phenomena of DIY-Materials that have emerged in the past decade and are growing exponentially. It was essential to understand why designers have embarked on this particular way of creating materials instead of selecting existing ones and, most importantly, how they do it. Cases Studies (Stake, 2000) helped to create a proper categorization of DIY-Materials into Kingdoms and Secondary Research (Booth et al. 2008 p. 76) allowing to analyse the different cases inside each kingdom while gaining qualitative data from each material.

The second part was devoted to testing the initial categorization working as a guideline to train designers to develop DIY-Materials. The course entitled "Designing Materials Experiences" was created to test the theories and hypotheses of this doctoral study not with an academic focus, but with a practical one, as it was important for this study to collect more samples developed within a controlled environment and compare them with the ones from previous studies. With a total of 97 participants from 32 countries in the first edition and 81 participants from 29 countries in the second edition, it was possible to develop a robust study. The methodologies applied in this second part include Creative Toolkits (Sanders & Colin, 2003), Prototyping (Martin & Hannington, 2012 p.138), and Storytelling (Beckman & Barry, 2009; Salomon, 2010; Giovagnoli, 2013).

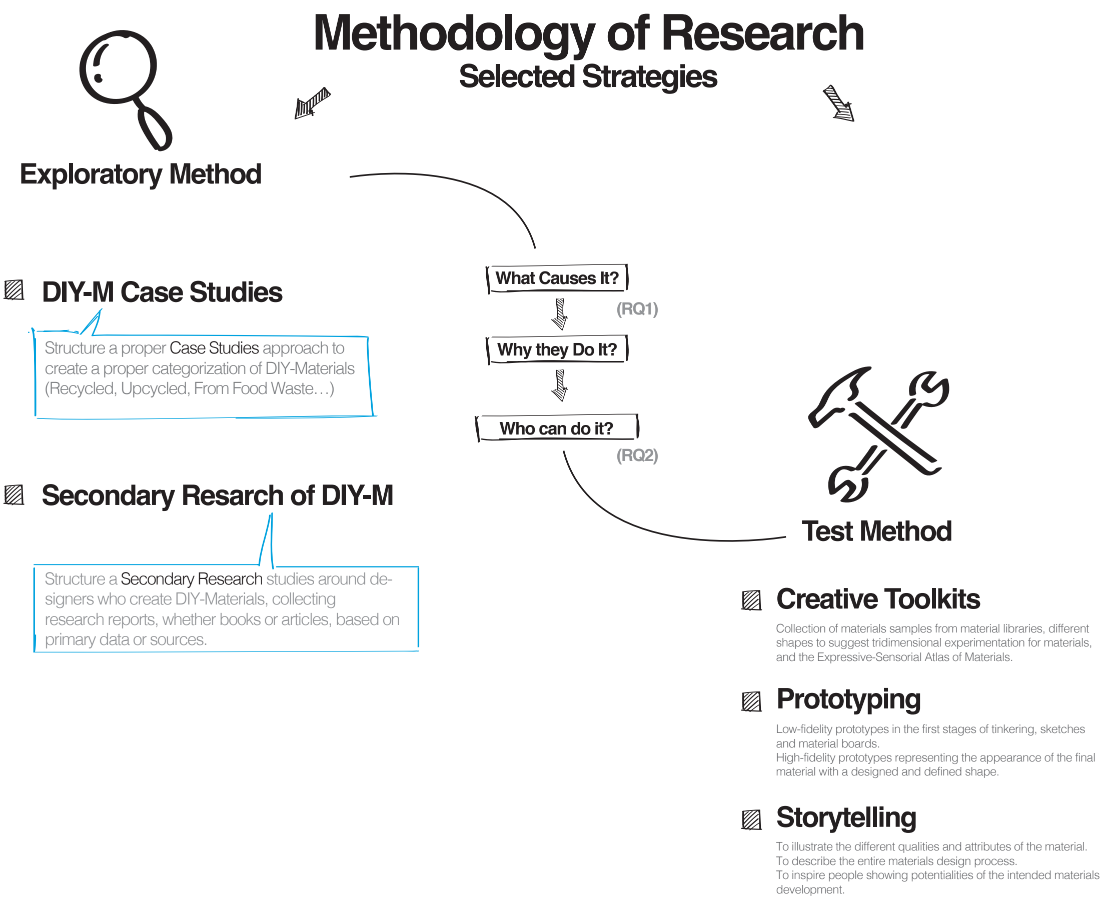


Figure 2.3
Methodology of research and the strategies performed during the studies.

2.2.1. Exploratory method

For the exploratory studies, the two selected strategies are:

Cases studies

Case studies are one of the most common ways to carry out qualitative research. According to Robert Stake (2000 p.437), there are three types of case studies: intrinsic, instrumental and collective. For this investigation, the collective case study strategy was more suitable, as it is a way to understand individual cases and recognise how some common characteristics manifest. Studying a collection of cases is believed to provide a better understanding of a phenomenon, population or general condition. It led to a better theorization of the research.

Secondary Research

Secondary research allowed for the analysis of the different cases inside each kingdom grasping qualitative data of each material. Different from primary research which implies a closer contact with the study subjects, secondary research allows for the collection of information from a variety of sources (Booth et al. 2008 p. 76). This strategy, together with the instruments for gathering information, also helps to suggest research directions to follow during the study.

2.2.2. Test method

For the test studies, the three selected strategies are:

Figure 2.4
Above: Samples from Materioteca.

Middle: Shapes to Suggest form giving.

Below: The Expressive Sensorial Atlas.

Creative toolkits

Understood as collections of physical elements conveniently organized to inform and inspire design and business teams (Sanders & Colin, 2001), this method allowed participants to gain familiarity with materials, understanding them by physical interaction instead of face-to-face lectures, typical in materials science. To this aim, different elements were introduced during the third and fourth study such as a collection of material samples from the "Materioteca" the material library of the Politecnico di Milano (http://www.materioteca.polimi.it/), shapes to suggest tridimensional experimentation for materials and the Expressive-Sensorial Atlas of Materials (Rognoli & Levi, 2005). This atlas is an educational tool aimed at helping designers study the sensorial qualities of materials as a translation of engineering properties (Figure 2.4).

Prototyping

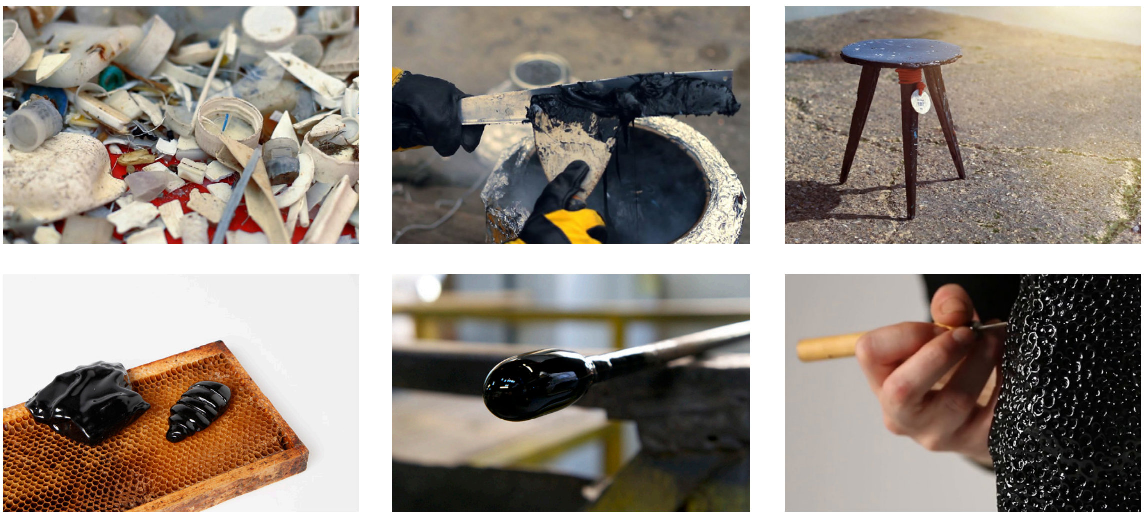
Prototyping is the physical creation of artefacts at various levels of resolution, for development and testing of ideas within design teams and users (Martin & Hanington, 2012 p. 138). A prototype allows testing physically different attributes of the designed element, in this case, the material. Transforming the material sample into a prototype means that some shapes, textures, finishes, and volumes become subject of study. This type of samples is critical not only to the designer but also for users to understand the intentions and features of a material. Design prototypes are defined by their level of fidelity or resolved finish. Low-fidelity prototypes appear in the first stages of tinkering accompanied by sketches and material boards. High-fidelity prototypes are more refined, often representing the appearance of the final material with a designed and defined shape (Figure 2.5). The participants are encouraged to move away from the standard flat, two-dimensional form of a material sample and to test the material through prototyping in three-dimensional shapes with multiple textures and colours. Contrary to what scientists usually do, trying to minimize variables, here designers test any possible skill acquired in their career, achieving unique results in every single prototype. The portfolio of material samples becomes incremental, and the tools for storytelling and envisioning become more productive and more stimulating.

Figure 2.5
Above: Low resolution prototypes.

Below: High resolution prototype.

Storytelling and material narratives

Storytelling is at the very heart of human cognition, of the interactions of individuals with one another and of the development of cultures in which humans thrive (Beckman & Barry, 2009). The field of design uses storytelling as a tool to describe the entire design process. It is used to inform the current stage of the project, or it is used to tell a new story, inspiring people by showing the potential of the intended proposal. When it comes to materials development, both types of



stories can become handy in illustrating the different qualities and attributes (Figure 2.6). Through the dissertation, it is possible to see different case studies with the designers telling the story of how they achieve a particular material and the whole meaning of this achievement. Others focus on how this material can open doors to new possi-

Figure 2.6
Example of storytelling from case studies.
Above: Sea Chair Project by studio Swine.

Below: From Insects by Marlene Huissoud.

bilities for parallel applications to contrast the current state of product development and mass consumption.
During the study, the participants received training in the different possibilities of what a story behind material development can do. This method allowed all teams to collect various data from the very beginning and organize it according to what the material vision proposed.

2.3. Research plan

The research plan consists on a series of milestones defined at the beginning of the research path. It is subdivided by years and contains the different studies proposed as well as the different steps performed (Figure 2.7).

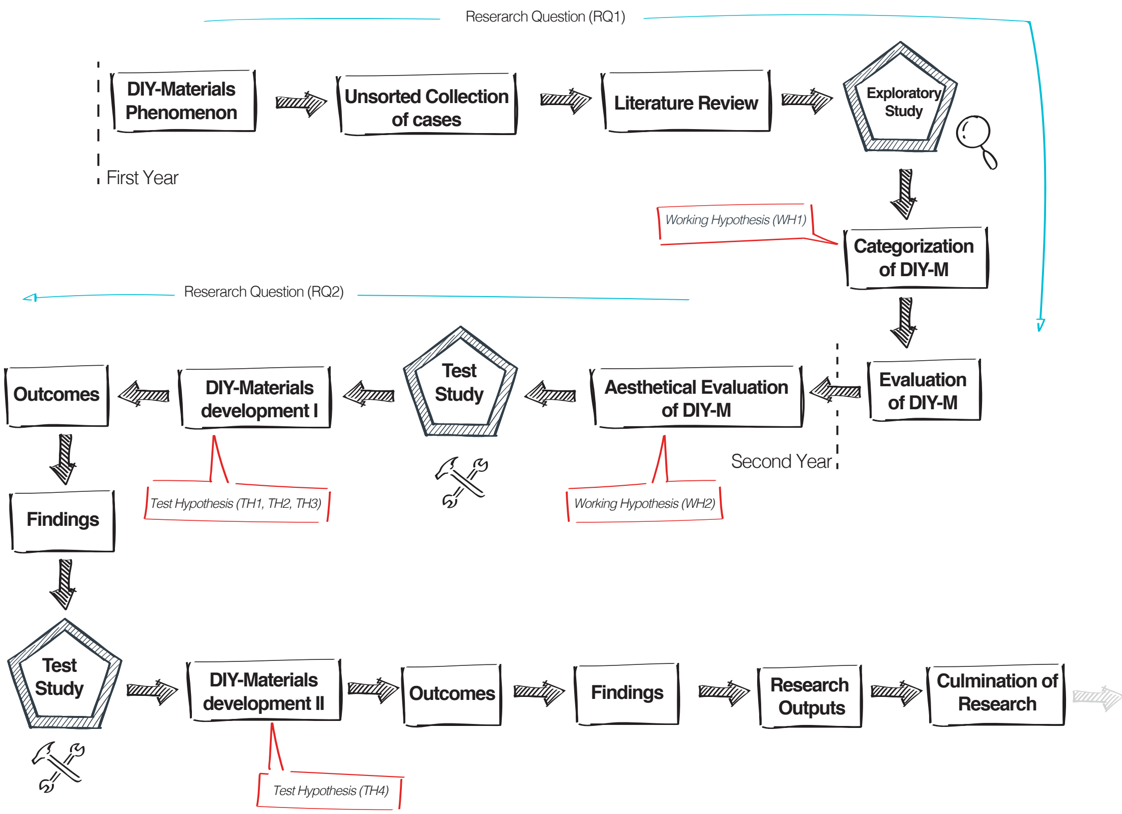


Figure 2.7
Graphical visualization of the research path.

2.4. Structure

The investigation was conducted first by understanding the theoretical background which was divided into the three macro areas of research. The analysis of the different elements of this theoretical background and the points of convergence resulted in the formulation of the first research question (RQ1). To answer this question an extensive collection of cases and an in-depth analysis of them began to give the research a sense of order. Different classifications and evaluations of the various cases studies collected became these exploratory studies:

- *Pre-Study*. Collection and analysis of 150 cases of DIY-Materials. This study resulted in the classification of cases by kingdoms and is published under (www.diymaterials.it). The cases studies are continuously updated in the open source database and analysed to extract qualitative data.

- *Study One*. Evaluation of the different cases studied with specific instruments allowed information to be gathered regarding the various motivations behind the creation of such types of materials.

- *Study Two*. Basic research on aesthetic qualities of the DIY-Materials classified by kingdoms. By gathering different qualitative tools and theories from various scholars, it was possible to establish an initial evaluation of the aesthetic and sensorial characteristics of these materials. This evaluation allowed for a better understanding of possible similarities and general characteristics of a kingdom.

With the exploratory studies concluded, the formulation of a second research question (RQ2) guided the second group of studies. Two courses at the M.Sc. level and five master thesis projects developed under strict guidelines provided the necessary data to move forward in the proposition of a DIY-Material theory. This second group of studies became the following test studies:

- *Study Three*. A course developed specifically to test the theories and methods gathered to create a material under guidance. Two editions of the proposed study happened during the research plan and provided insights to validate hypotheses.

- *Study Four*. Added another layer into the development process creating a series of incremental steps for advanced DIY-Materials development. Five participants from the previous study with the potential to develop an M.Sc. thesis on DIY-Materials were selected. Their topics for thesis work and their investigation were guided to prove hypotheses and provide additional information for the DIY-materials theory.

The different research questions, hypotheses and the related studies in correspondence with the chapters of this dissertation are visible in figure 2.8.

Study		Research Question		Hypothesis
Pre-Study	(RQ1)	What causes the DIY-Materials Phenomenon?	(WH1)	- The DIY-Materials phenomenon tends to grow. There should be a way to organize it to allow a better understanding.
1st Study	(RQ1)		(WH1)	
2nd Study	(RQ1)		(WH2)	- If DIY-Materials emerged from the creative fields of humanities, then there is a gap that traditional material related sciences are unable to fill.
3rd Study	(RQ2)	Who can generate a DIY-Material?	(TH1)(TH2)(TH3)(TH4)	- If somebody who knows how to craft things get additional knowledge and guidance about how to perform a materials development, then he or/she can produce a material sample of any kind.
				- Starting material development from a particular source has an effect on the final material developed.
4th Study				- DIY-Materials were the result of motivations other than what STEM materials commonly have.
				- If DIY-Materials achieve a mature level of qualitative development, it is possible to analyze them with standard methods to reveal qualitative data and with the combination of data propose possible paths towards an application.

Figure 2.8
Overview of studies with focus on research questions and hypothesis.

2.5 Context

The overall research was conducted in an academic context first by analysing the phenomenon of DIY-Materials within the design field and with empirical research tools known in the design domain. Subsequently, the test studies took place within the design department of the Politecnico di Milano, and all participants were Master students. They accepted to be subjects of research and agreed to share their findings and contribute to the theory's formulation as presented in this dissertation. Although the whole investigation was conducted and analysed within academia, the different outcomes of this dissertation have the potential to be explored outside an academic environment through the various streams proposed in **chapter nine**. Different dissemination work is already published, and other open source material is being prepared to reach a broader audience.

2.6. Intended Outcomes

The dissertation presents the different achievements of the doctoral study, aiming to better understand the phenomenon known as DIY-Materials. A theoretical background based on a taxonomy of the different materials collected allows for the interpretation of the motivations behind the designers who create those materials and will seek to establish directions for this type of developments.

A practical method composed of a series of steps which allows for the development of DIY-Materials with a high level of quality is considered as an outcome of this investigation. The second part of this dissertation which is called the test phase shows an in-depth explanation of how the different subjects of the study experienced a DIY-Materials development process. During this process, participants produced a series of samples following different directions and methods.

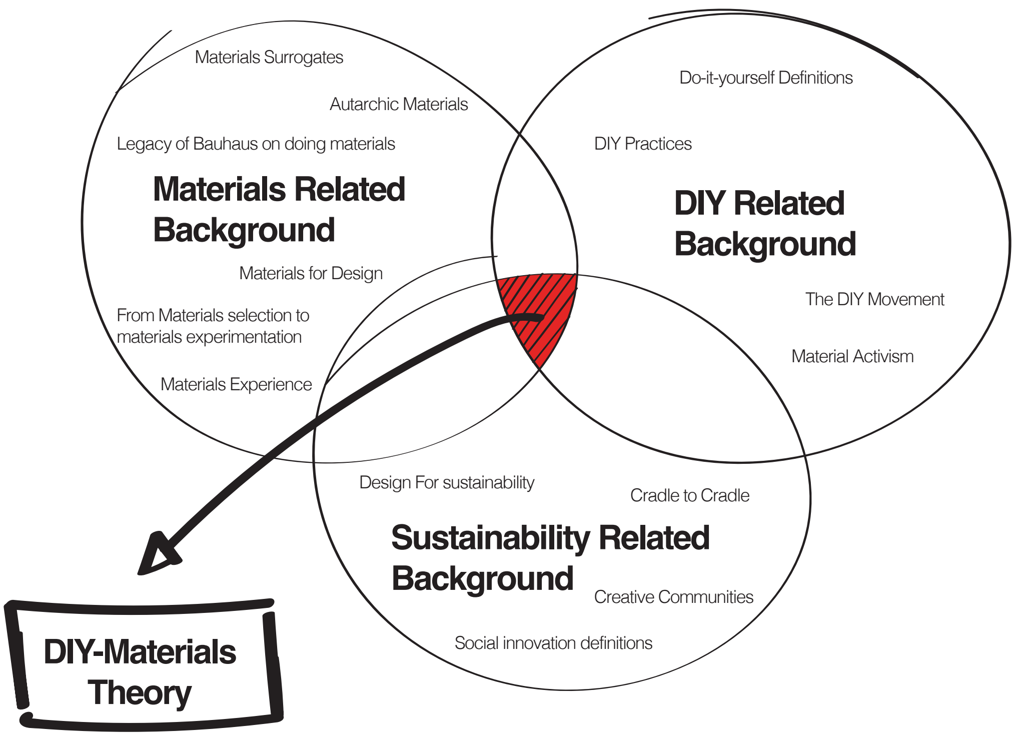
An open source database with the results of both explorative and test phases is available to anyone who decides to replicate a material, propose a new alternative or continue the development of material given a specific application. The Ph.D. started by collecting cases and moved towards the creation of new ones. By building a database organizing previous cases and newly developed ones together and in a visible manner, the investigation will open the doors for more designers to perform and develop these new emerging materials experiences.

Chapter Three

Theoretical Background

To build a proper theoretical background, the literature review is summarized and focuses on the different macro areas of research to better connect with the investigation. The three macro areas of research contain important facts and theories from various fields of knowledge. It is in the interlaces and interconnections of the three macro areas and their particularities where the DIY-Materials phenomenon is best understood (Figure 3.1). Each macro area of research can expand and a more significant debate about each topic could lead to other investigations. Still, for this particular research, the intersection of the three areas provided enough theoretical input to perform the studies and propose further developments.

Figure 3.1
The three macro areas of research and where the DIY-Materials Theory is placed.



3.1. Materials related background (First Macro Area of Research)

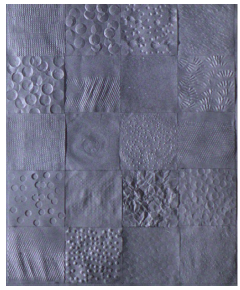
3.1.1. Legacy of Bauhaus on doing materials

The Bauhaus was founded in Weimar in 1919. In the first phase, the Bauhaus was oriented into expressionism and motivated by a community spirit. A person who influenced the school during this initial period was Johannes Itten. Itten worked from 1919 to 1923. During this period, he created preparatory courses (Vorkurs in German). The classes became the structural foundations and played a vital role in the learning process of the designer. The foundations studied nature and materials with a strong emphasis on the theory of contrasts. Through them, it was possible to enhance sensibility towards materials and they prepared students for their future work in laboratories. Upon completion of the "Vorkurs," the student could move to the laboratories and spend another three years.

In the preparatory courses, Itten also began with the studies on materials, textures, finishes and phenomenological aspects. Before any technical description, the expressive and sensorial characterization of the matter was considered fundamental for the education of the future designer. The study of nature and materials aimed to show every essential aspect of each particular material so the student could tune its sensibility towards materiality. Students demonstrated the character of materials by experiencing visual and tactile sensations in contrasting physical samples of wood, glass, fabrics, bark, furs, metals, and stones (Figure 3.2). The first contrasts such as smooth-rough, hard-soft, light-heavy were not only seen but also felt.

In 1923, Itten left the school and was replaced by Lazlò Moholy Nagy who provided a more educational approach influenced by the constructivism movement regarding aesthetics. New pedagogical reform moved the school from the centrality of the individual to focus on the creation of a new series of products with the aid of the emerging industries. The development of an objective and technical perspective create unity between art and technology.

Josef Albers, an alumnus who became "meister" in the same year, focused his work on developing a strong connection with the industry. Students were requested to elaborate all kinds of objects not with the industrial tools, but with available and low technological ones. Albers also taught notions around physical properties of materials and



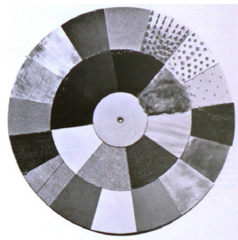


Figure 3.2
Above: Gerda Marx 1927, One material different tools.

Below: Walter Kaminski 1927, Tactile wheel.

Students work from Bauhaus Vorkurs.

construction fundamentals (Gropius, 1979 p.269). When Albers understood how factory visits influenced the students to a more imitative approach, he decided to relaunch a "Vorkurs" with two fundamental pillars: exercises with matter and exercises with materials.

In the first one, the focus was on the exploration of the external appearance, the epidermis of things, sensing matter through contrast and relationships. In the second one, the focus was on the study of the material, with a strong emphasis on a systemically approach. Materials should be worked in a way that does not generate any waste. The economy was the fundamental principle (Droste, 1990 p.34). Moholy Nagy, running in parallel with Albers, explored the concept of composition. "For Moholy-Nagy, the question of the social relevance of aesthetic production was one of central importance; for Itten, by contrast, artistic activity was primarily an individual problem" (Wick, 2000).

The lectures of Moholy-Nagy concentrate on the composition of original and diverse materials. Among those were found the new synthetic polymers, where researches around new perceptive-aesthetical aspects such as transparency and homogenous surface were the object of investigation. Reusing the tactile tables from Itten but under a more futuristic influence, tuned sensibility to the students towards the materials. The parallel work of Moholy-Nagy and Albers gave students a material knowledge from both technological and expressive sensorial dimensions. This was the key evolution and legacy from what Itten had previously proposed.

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Similar to what happened during the Bauhaus at the beginning of the twentieth century, one hundred years later is possible to witness a comeback of studies of materiality both from the technological and expressive dimension. Designers are willing to explore the matter again to discover sensorial qualities and enhance their creations with new materials and new transformations of existing materials.

3.1.2. Autarchic Materials

It is well known that the research towards polymers started actively in Northern Europe and the United States. What was precisely happening in Italy at that time? Between 1935 and 1936, imports were subject to government authorization, which impeded the operation of industries. Such a system was imposed as a response to the different protection measures and the sanctions towards Italy by different countries. These restrictions drove the Italian economy towards a complete autarchy. This autarchy allowed the industry to flourish and many technological and scientific innovations emerged during this period. However, many of these innovations were pushed by imperial autarchic military goals. The research on materials had a keen interest in developing new semi-finished products such as Linoleum, Faesite, Masonite, light aluminum alloys, and glass. All materials that were produced in northern Europe some decades before, but in this case, the materials should be developed entirely "at home" from the extraction of raw materials, to the manufacturing process (Bosoni, 1983). According to Vittorio Gregotti, in the period between world wars, a significant number of materials emerged and moved the Italian economy in complete isolation with high standards of innovation, exploiting their resources. This drove the Italian industry forward, resulting in many achievements that became key to consolidate the different well-known sectors recognized today in the design arena (Gregotti, 1986 P.185).

Within this autarchic climate, Giulio Natta started his research activity. Politics and autarchy encouraged chemistry to search for new materials. The same was happening in other parts of the world too. But looking at how this search was ongoing in Italy, a key factor links this autocratic period to this dissertation: dealing with the autonomy of resources from extraction, to production. During the period where Natta conducted his research, he developed the PP (isotactic polymer) and won the Nobel prize (Figure 3.3). Simultaneously, different industries around the world were relying on industrial designers to change the image of polymers for the general public. Raymond Lowey, Charles Ray Eames among others belonged to this wave. In Italy, the "good Italian design" found in the application of polymers represented the values and experiences that many were struggling to obtain and became the basis of what industrial design was all about.

Figure 3.3
Giulio Natta at Politecnico di Milano observing results while experiments with polymers.

From Kartell or Guzzini towards Pirelli and Arflex, it is possible to find a broad portfolio of companies that invested in their brand relying upon the material and the products (Rognoli & Levi, 2005 p. 21). The number of designers that were applying their concepts to the new polymers grew more in Italy than anywhere else. An example of this wave is visible in the International Exhibition of the aesthetics of plastic materials (Mostra Internazionale sull'estetica delle materie plastiche) showcased during the 1956 Fair in Milan made by the Stile Industria Magazine and curated by Gio Ponti (Figure 3.4). This event was of great importance for both the industry and the designers. The exhibition reunited around 160 industrially produced objects coming primarily from Italy, as well from the United States, England, France Denmark, Sweden, Finland, Switzerland Germany, Canada, and the Netherlands but in a lower scale. All products were with an advanced qualified expression of industrial design made with polymers. The exhibition is considered of great importance in the field of materials and design, as it showed the link between a novel material and the capacity of the designers to take the best of it and apply it to design.

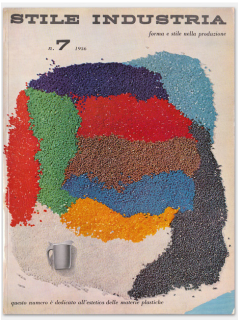


Figure 3.4
Stile Industria Magazine from 1956 dedicated to the aesthetics of plastic materials.

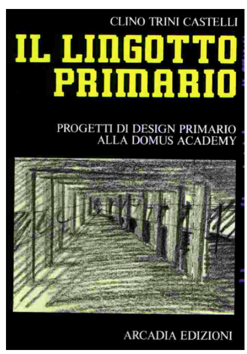
In the article called "The Good or bad use of plastic materials" by the engineer Giulio Castelli, a former student of Giulio Natta and the founder of Kartell, expresses important statements about the role of designers and the relationship with materials. Castelli believed that designers should always be together with the president of the company in the highest hierarchical level of an industry as designers are more than mere form givers, and are, in fact, capable of understanding the whole production cycle (Castelli, 1956). From that moment on, the designer's intervention into the project was significant from the functional and applicative side, but above all from an expressive-sensorial one. The role of the polymers was fundamental for industrial design during the fifties, but also the role of industrial design was fundamental for the development of polymers (Riccini, 2003 p.55). This reciprocal influence between materials development and design has happened in the past and is happening today as will be visible through this dissertation. Periods of autarchy together with the low availability of material drive designers to explore alternatives with the resources they have in hand. During the autarchic period in Italy, designers pushed a whole industry to grow by understanding materials from a multidimensional approach.

3.1.3. Materials Surrogates

The concept of surrogates in the materials field can be traced in the whole history of humans. However, this concept has been emphasized during the consolidation of the industrial model. The polymers, since the earliest developments of the nineteenth century are considered the surrogates par excellence. At the beginning of that century the development of a material known as Linoleum (Linen oil mixed with cork and printed over a jute textile structure), emerged as a cheaper surrogate to replace expensive wood and marble flooring. Many industries, particularly in Germany invited artists and designers like Peter Behrens to transform an inexpensive material into revolution (Ziegler, 1983 p.71). Surrogate materials tend to be considered not only substitutes of another material, but also a substitute of lower quality than the original one. In the history of materials, it is possible to trace in different moments, how each material discovered by humans are used as surrogates of other precious ones. Glass to replace gems and precious stones, earth ware to replace majolica and porcelain, and so on. The majority of materials which enter in the industrial world enter as surrogates of lower value than the ones they are called to replace. This value is not only economic but also sensorial as the expressive quality of the original material remains in the imaginary of the society. The new material has to pass through a maturation process before society begins to consider its intrinsic values. This maturation stage, however, is recently changing, as many materials especially the DIY-Materials appear as surrogates of materials that are either harmful to the environment or where common applications where the material is commonly used reach a stage of overproduction and over disposal, paradoxically, like what is happening to polymers in this century. In conclusion, surrogate materials offer an opportunity as alternatives and when designer consider, develop and apply them to their projects, innovation through materials is always possible.

Figure 3.5
Above: Cover of the Domus magazine of 1983 featuring the new Domus Academy with Andrea Branzi, Antonio Petrillo, Alberto Meda, and Ezio Manzini as proffessors.

Below: Il lingotto primario book by Clino Trini Castelli.



3.1.4. Materials for Design

Materials for design is seen nowadays as a well-defined subject within the design domain. To understand it correctly, it is essential to highlight important theoretical and project experiences that took place during the seventies and the eighties of the last century. Between 1973 and 1978 in Italy, a particular study emerged which moved the design project towards a qualitative dimension of materials and the relationships and iterations between objects, spaces, and people around their

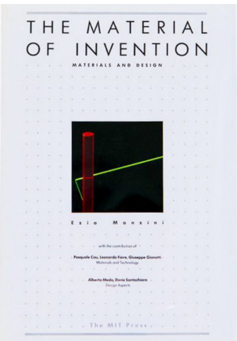


Figure 3.6
Above (a): L'uomo tronico (Man-tronic) by Antonio Petrillo.

Below (b): Cover of the Matter of Invention book for materials and design by Ezio Manzini.

daily experiences. Defined under the name of "Design Primario" this emerging field of study focused on the different chromatic, acoustic and tactile qualities, and was able to elaborate languages where the expression of the material tends to prevail over the overall structural and formal dimensions of the project (Pansera, 1995). Clino Trini Castelli, Andrea Branzi, Antonio Petrillo e Massimo Morozzi conducted the research on this field at Domus Academy and aimed to move the attention from what they called the hard qualities of materials (shape, structure, and performance) towards the soft qualities of the materials (Figure 3.5). Soft qualities such as colour, light, microclimate, decoration, smell and music, which have always been considered secondary became critical elements in the development of a project and are explored with priority (Petrillo, 1985). The outcomes of the Design Primario were not explicitly intended for a particular application or to design new products. Instead, the researchers developed a series of semi-finished materials and theme instructions to give to designers to work. The fundamental contribution of this research relies on the fact that sensations are, above all, active elements of a design project (Figure 3.6 a). Materials and technologies acquire a role not only with an aim to shape and construct a project but also aiming to provide expression and sensoriality into it. Selecting a material is determined by the language, the perception, and the emotion. During that particular period, the Italian design opened an original track regarding the project culture: The design of materials intervening where the material is acquiring its chromatic, acoustic, visual and superficial qualities. In this dimension, the material acquired an identity that is specific and culturally recognizable (Doveil, 2003). The design of materials opens new possibilities for the project, intervening not on the shape but the material definition of the product (Branzi, 1984 p.112). The need to design the material, independently and above the shape of the object, is to enter into industrial processes paying close attention to expressive and sensorial components. For this aim, it is essential that the two disciplines involved (design and engineering) are able to communicate. Old and new materials, artificial and natural ones, poor and precious live in the same dimension, but they become gain added significance when are involved in a project. This project determines the different qualities and the identity of the materials that will distinguish a product from the others. The field of materials for design does not only focus the discovery of new materials never used before. It also works with common materials which need a definition of their qualities

(Manzini & Petrillo, 1991). New materials do not always refer to a small number of sophisticated materials tuned by some scientific sectors towards an advance application. They signify some qualities that encompass a material (even if is a material used for ages), repurposing it into a new productive process wrote Ezio Manzini in what is considered one of the foundations of the materials and design literature, The Matter of Invention (Figure 2.6 b) (Manzini, 1986 p.17).

3.1.5. From Materials selection to materials experimentation

The last decade of the past century was the scenario of one particular phenomenon that is still visible today: The flourishing of the materials libraries. They were born to provide a service to designers and architects who were looking for a broader source of inspiration and to find the right material for their project. Like a library of books, these are repositories of knowledge, but instead of books, they contain materials (Miodownik, 2007). Many designers and architects used to gather material samples and create their private collection of materials in the past. However, these new spaces present themselves to be more than just a collection of samples. They are places to meet. Designers, architects, engineers, and industries encountered in these material libraries. These were spaces whether they interacted and met to start projects. Rigorous classification and archival knowledge are put into the material libraries to provide together with the material sample all the information needed to find an application. Material libraries can have an academic or business orientation. The first ones are places to inspire, teach and connect future designers with different technologies, processes, and resources. The second ones are mediators between two types of clients. The user/designer client and the company/provider client. The business stays in the middle as a service. From a theoretical point of view, it is possible to recognize the role of material libraries in the relationship between the designer and the manufacturer. These spaces became a resource for people to understand a material actively by a sensorial interaction (Rognoli & Levi, 2005 p. 49). Different from the private collection that designers and architects gathered through the years and were based on their projects, the material libraries offer a broader and updated selection of materials and technologies. According to Ashby and Johnson:

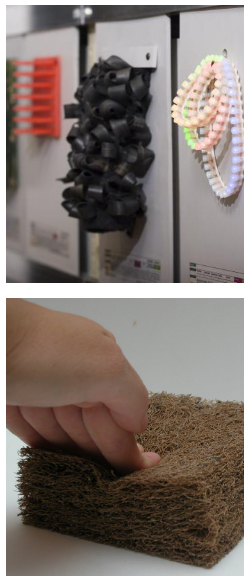


Figure 3.7
Above: Material Libraries display of samples.

Below: Physical interaction with a material sample.

"Many individual designers and design houses assemble collections

Figure 3.8
Above: Materials selection with CES from Granta.

Middle: Materials selection with the Nike MSI App.

Below: Materials selection with the Materfad web platform.

of materials, not just metals, plastics and ceramics, but also weaves, finishes, coatings, and shapes. Materials that have, in various ways, been processed. The physical nature of the samples is the key point: new ideas – inspiration – can come more readily from handling (not just visualizing) a material" (2002).

In the material libraries, the designers find similar opportunities but on a higher level of complexity. The selection process of materials and technologies becomes a hyper-selection process (Manzini, 1986 p.37). They are an augmented resource whereas for a product, there is not only one possible choice. Different materials and technologies compete for a place in the project across multiple dimensions (Figure 3.7. In the history of technology, new materials appear to provide a performance of a particular kind that used to be a consolidated territory of other materials. Simultaneously those new materials open possibilities for new applications that were previously difficult to achieve. The material libraries are the contemporary scenarios for such things to occur, as there is a lot of room for creative inspiration by experiential interaction with different materials.

Another side of the material selection process deals with the use of software, apps or virtual material libraries (Figure 3.8). These are tools that work, but are far from what physical material libraries can do (mainly as the experiential interaction with materials using such tools become possible only through sight). Still, virtual tools are useful resources, as it is possible to filter and select materials based on their characteristics and type of performance required from a material. They are based on the principle of property mapping (Miodownik, 2007). This principle enables the understanding of complex properties of materials such as resilience or stiffness into something clearer for a designer like elasticity or durability.
The CES software, as well as the different virtual material libraries, allow narrowing a material selection to a few samples by filtering properties, qualities, and environmental issues. These resources are useful in all the places where material libraries do not exist. In those places where access to materials on a large scale is limited or unavailable, it is possible to find a sort of initiative that connects better with what this dissertation is about: Materials experimentation. Although the stream of material libraries and material selection tools are still in use and are increasing in the universities and major cities around the globe, the

idea of experimenting with materials instead of selecting existing ones is becoming radical.

it is not a new idea. As expressed at the beginning of this chapter, designers in the Bauhaus were trained not to work with the material but work through the material. Something similar happened in the sixties when designers entered into the complex scene of scientific material development to contribute with their knowledge to provide a sort of identity to those new materials. Nowadays the consolidation and democratization of specific technologies together with the access to different sources of information are allowing the designers to take the materials in hand again and experiment with them, proposing new materials. Manzini states that materials can also be considered new when a creative combination of known materials produces them. Those new materials do not necessarily appear as a result of researches inside laboratories. They emerge in any scenario where the new materials culture intersects the creative capacity (Manzini, 1986 p.42). Designers are opening up to materials recently, and they are using their creative background to enhance them. This is being done not only by increasing performance but also by enhancing the material experience that the materials could bring to the product.

3.1.6. Materials Experience

Materials Experience is one of the growing interests' designers are approaching towards in a conscious way. Materials like products can evoke emotions (Hekkert & Karana 2014 p.7), therefore when people interact with products, the embodied materials provide several reactions that can enhance or diminish that particular experience. Materials Experience as is known today has its basis in what Aristotle stated in the past by saying that sensations are the mirrors of reality and therefore senses are true sources of consciousness (Aristotle, 2001). This is because of senses that people can perceive materials and therefore understand them through what is defined as expressive-sensorial qualities of materials and experiential qualities of materials. Those qualities can not only be considered, but can be furthermore measured (Rognoli, 2004).
Since the time of Galileo Galilei, science has questioned physical phenomena of life (Massirony, 1998), and the constant inquiry of objective quantitative data has become standard practice even when it comes to research of materials. Physical qualities of materials be-

Material	W/mK
Cooper	384
Aluminum	230
Glass	1.1
Solid Polymers	0.15 - 0.35
Pine	0.112
Balsa	0,055
Cork	0.045
Glass Foam	0.050
Mineral Fiber	0.046
Glass Wool	0.042
Polymer Foams	0.02 - 0.10

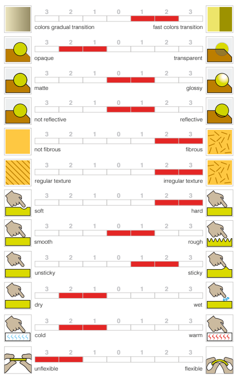


Figure 3.9
Above (a): Surface temperature measurements. (Ashby and Johnson).

Below (b): Sensorial scales (Karana 2009).

came the focus of study for many scholars afterwards, leaving little or no room for sensorial studies around materials. Ashby and Johnson (2002) created what started to be seen as the possible approach of science to understand the sensorial qualities of materials. In their book Materials and Design, one can see that sound perception can be measured by formulating acoustic pitch and brightness, or material appearance can be measured by understanding the light transmission properties of a material; even the way a material temperature is perceived can be measured by watts per square meter of surface area for a temperature gradient of one kelvin for every meter of thickness (W/mK) under the technical name of thermal conductivity (Figure 3.9 a). But Materials Experiences go beyond all this. Some building blocks of research have also been developed to understand from a designer's perspective how to measure and understand those expressive-sensorial qualities of materials that enlighten material experiences (Van Kesteren, 2008) (Karana, 2009) (Rognoli, 2010) (Zuo, 2010) (Howes & Classen, 2014) (Figure 3.9 b). With those building blocks in hand, selecting materials for a designer is not only a matter of understanding physical properties (which is essential), but also for understanding expressive-sensorial qualities of materials. Humans experience materials on the basis of the characteristics of a situational whole (Giaccardi & Karana, 2015). This is the reason why both technical and perceptive properties materials are needed.
The evolution of the materials experiences framework is constructed along a method called Materials Driven Design Method (Karana, Barati, Rognoli, Van der Laan, 2015). In this method, the material is at the center of the creative process, giving it the possibility to drive any further project or product development.

By addressing this framework of materials Experience together with the MDD method, this macro area of research will provide the tools to find possible points of interactions with the other two macro areas that exist in this doctoral research. One should keep in mind that a material should be socially and culturally accepted or acceptable (Manzini, 1990) (Manzini & Petrillo, 1991). For this purpose, self-made materials can become accepted within the society or a particular culture probably if the people who create them are embedded in that society or culture.

3.2. DIY related background (Second Macro Area of Research)

3.2.1. Do-It-Yourself definitions

There has been a long debate around the differences between an activity performed by professionals, for instance designers in an established cycle of creation, production and consumption of goods; and the more amateur design and production activity carried out by the end user known as the Do-it-yourself, which is a as a more democratic process that is self-driven and self-directed. (Atkinson, 2006 p.1). Since the eighteen century, a bifurcation between organized industrial processes guided by control and accuracy on one hand, and the loose semi accurate processes of traditional crafts on the other, still exists. During the post-war periods and because of scarcity and shortage of labour, the Do-it-Yourself practices gained acceptance amongst most people as a democratizing outcome that allows people to create their own goods (op. cit). Later on, when the market became oversaturated with industrially produced goods and given the fact that the society was giving DIY practices a possibility to value creation through the involvement of the consumer in the co-creation of a project, the term prosumer appeared on to the scene (Toffler, 1980) (Wolf & McQuitty, 2010; 2013). "Prosumtion activities are defined as consumers producing products for their own consumption" (Xie, et al, 2008).

Going deeper into the definition, Kotler (1986) describes a specific form of prosumption as Do-it-yourself (DIY). He defines DIY as "activities in which individuals engage raw and semi-raw materials and component parts to produce, transform, or reconstruct material possessions, including those drawn from the natural environment". Nowadays, DIY practices are being empowered with technological open-sourced access that is emerging as a way for prosumers to obtain full control over those activities (Anderson, 2012). Therefore, these dynamics around DIY practices have led to the emergence of new materials for product design (Rognoli, et al. 2015).

It is interesting to note how in the recent years a series of initiatives around the world have flourished in terms of Do-It-Yourself practices. This shows a different approach where designers gain control of the whole project by giving birth to a product in complete autonomy.

Materials processes and distribution channels are controlled by the designer and the project don't rely on external stakeholders to succeed.

3.2.2. DIY Practices

Figure 3.10
Above: DIY aluminum melting machine. Studio Swine.

Below: DIY Printing Machine. Blond and Bieber Studio.

The DIY practices can be better understood by analysing the new waves of technological advancements. As explained before, the renaissance of the craftsmanship (Sennet, 2008) enables designers to self-produce, by combining the making, crafting and personal fabrication processes (Figure 3.10). Anderson (2002) states that custom made developments have been forever. The difference appears when the DIY culture suddenly meets the web culture. In other words, many of the practices that allow designers to become new crafters, even of materials, are supported by a mix of analogue and digital tools (Gershenfeld, 2005; 2012). The technology sources are a mix of bits and atoms (Negroponte, 1996) sometimes only atoms, and sometimes more bits than atoms. Under these conditions, it is possible to see that sometimes the designer creates the tools to develop the product. The DIY practices are an alternative response to wicked problems (Rittel & Webber, 1973). Wicked problems are according to the authors:

"a class of social system problems which are ill-formulated, where the information is confusing,
where there are many clients and decision makers with conflicting values, and where the
ramifications in the whole system are thoroughly confusing."

This means that all problems that are considered "wicked" such as global climate change, social injustice or contamination of the oceans are hard to tackle and rely primarily on political judgment for resolution (op. cit). DIY practices become an alternative and several times it is possible to achieve better results building on DIY than following a more scientific approach where sciences try to find solutions. The DIY subculture can do things that work the same or better than the traditional infrastructure of the society (Lukens, 2013). Designers are activists of DIY practices as they deal with human interactions. This interaction attempts to build a new series of socio-ethical systems.

3.2.3. The DIY Movement

DIY practices are typically rooted outside any professional activity like design or architecture (Edwards, 2006). It is considered an individual activity, but, some scholars argue that thanks to the trends of knowledge sharing via web platforms it has evolved as a social activity (Bean & Rosner, 2012). There are around the globe several platforms that enable DIY practices to be shared. It is possible to find in such platforms both expert professionals and amateurs together developing an intended project exchanging ideas for mutual benefit (Anderson, 2012; Torrey, Churchill and McDonald, 2009; Kuznetsov & Paulos, 2010). It is clear that these initiatives do not represent a threat to industrial manufacturing and large scale production. Still, they represent an alternative to mass consumerism and become a representation of democratic innovation through information sharing (Mellis & Buechelly, 2014). When it comes to the field of design, it provides another alternative for what is mostly considered Industrial design. The classic industrial designer is formed to provide meaningful input to a specific industry with proper skills of the discipline and is an active part of the different wheels moving the market. However, the DIY design movement (Camburn & Wood, 2018) is highly influenced by the user instead of the market trends, primarily as often the designer is the final user. This change of perspective allows that personal fabrication can reach the market with free modelling software (Mota, 2011), distributed manufacturing networks accessing components and materials directly from suppliers (Anderson, 2012) and large online selling platforms. This phenomenon creates alternative means of production as well as transform the behavior of consumption of goods. Sooner, materials development will enter in this network as designers are transforming materials coming come either from raw sources or by recuperating available local ones from the same networks.

3.2.4. Material Activism

The term “materials activism” was firstly coined by Miriam Ribul (2014) as an expression to identify a low-tech approach that would democratize the production and development of materials. In her open source publication (Figure 3.11), Ribul invites through a collection of recipes for in-house material experimentation, an understanding into the possible paths for developing alternative materials creating new aesthetics and new materials languages.

The concept of “activism” is introduced here as a provocative exhortation to the designers to start a vigorous protest against the closed sys-

Figure 3.11
Material Activism book by Miriam Ribul.

tem of materials development of the industry (Rognoli & Ayala-Garcia, 2018). This industrial system often excludes designers by the lack of scientific knowledge. The designers rarely have access to the development team composed mainly of Engineers and Scientists when the market requires a new material development. In this particularly rigid industrial system with plenty of barriers to entry, designers employ materials and processes already available in the market for designing. In other words, designers have become experts in material selection or select materials thanks to instruments available as explained in the previous section.

In the past two decades, a new appreciation of craftsmanship has emerged. (Bardzell et al., 2012; Bean & Rosner, 2012; Bettiol & Micelli, 2014; Sennett, 2008). Some designers recognize themselves as belonging to this category. The new craftspeople are able not only to understand and transform a particular material but also to control the technologies of transformation, while being interconnected with other artisans around the globe. This new craftsmanship renaissance is known also as the Makers Movement (Anderson, 2012). This movement, in many cases encouraged by the internet and the open-source philosophy it supported and promoted the new industrial revolution. This revolution became the fertile ground for materials activism to appear. The democratization of the means of production, combined with the people`s wish for personalization and appropriation (op. cit, p. 102), have opened an alternative to the closed system of industrial materials development. Also, it enables the designer to start any materials experimentation experience that he or she may find interesting, using any inspirational sources (tutorial, shared previous experiences and so on). After some iterations with the material, the designer may also go and buy any open-sourced instrument that can help improve what he or she has created. Suddenly, the designer belongs to the emerging big group of activists that create a project starting with the material development.

Some decades ago, the scenario described above was impossible to imagine as the materials and processes were always developed and improved in a closed system inside labs and Industry´s R&D sections and not at home or workshop.

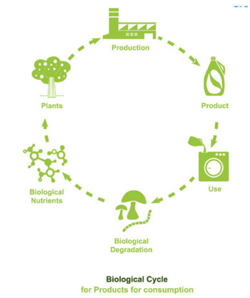
3.3. Sustainability related background (Third Macro Area of Research)

3.3.1. Cradle to Cradle

Another theoretical background that is of extreme importance for this research is the work of Michael Braungart and William McDonough known as Cradle to Cradle. In this book, the authors develop a concept which will become one of the building blocks of the theories supporting the creation of a circular economy. The idea proposes a kind of new industrial revolution which consists of the division between the natural processes and industrial processes in what they called "two metabolisms" (McDonough & Braungart, 2002 p.103). Such separation generates stability in both, our societies and in the ecosystems (Figure 3.12). The primary metabolism, called biological metabolism, suggests that humans through the right selection and application of biodegradable materials, provide the opportunity to circulate them inside the ecosystems. By doing so, every time a cycle of use finishes, those materials become natural nutrients for the planet. The secondary metabolism, called technical metabolism, is an invitation to conceive projects with non-degradable materials in such a way that those materials could circulate inside this metabolism, transforming into nutrients of this system, perpetually feeding industries.

Another concept proposed by the authors which is crucial for the DIY-Materials research deals with the elimination of the idea of waste (op. cit, P.104). When designing products and materials with life cycles that are healthy for societies and the environment divided into the previous metabolisms, it is possible to feed both systems perpetually recovering the value of materials. By removing the idea of waste from the brain, it is easier to understand and deal with two types of nutrients. The biological nutrients, which are all materials and products that through their use, are consumed losing the chemical structure that holds them as a unity, and the technical nutrients, that are used by people until they are no longer needed or became useless.

The last concept which is fundamental for the DIY-Materials research is the concept of eco-effectiveness (Figure 3.13). In this triangle based model, environmental and sustainability issues are connected with economic profit and social equity. When commerce ignores sustainability both in the ecosystems and in the society, it produces large scale tragedies destroying valuable natural and human resources (op.



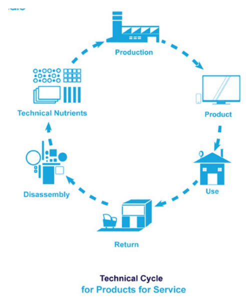


Figure 3.12
Above: Cradle to Cradle Biological Metabolism.

Below: Cradle to Cradle Technical Metabolism.

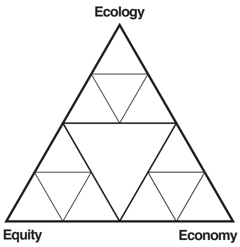


Figure 3.13
Eco-effectiveness triangle model.

cit., p. 150). On the contrary, when every venture that takes place considers the three elements (Ecology, Equity, and Economy), there is a high chance that can produce well-being to all stakeholders, it will maintain the ecosystems respecting the natural flow of life, and it will produce sufficient profit to carry on as humans. According to the authors: whatever profit it takes to raise a family everywhere on the planet. As materials are the building blocks of our society, this consideration of the eco effectiveness must always be considered. DIY-Materials are rooted considering the three actors of the model: people, planet and economic profit.

3.3.2. Design for sustainability

Sustainability is an issue that is no longer considered optional in a design project. It is crucial to examine the impact of every action and every intention inside the project as it is bound to have a positive or negative consequence in the future. In early 1972 a report for the club of Rome's project on the predicament of mankind highlighted, for the first time, the limits of growth (Meadows et al., 1972). In an unprecedented way, this publication showed the planet earth as a finite system. The connections with population increase, food production, industrialization, pollution and consumption of non-renewable natural resources, and the yearly amount of increment highlighted a pattern of exponential growth (Figure 3.14). Thanks to this analysis it was possible to understand that our societies needed to change dramatically to assure a sustainable future for the planet. Since then many approaches to reduce the impact of humankind on earth have started. Today some societies are moving from a linear economy of taking, making and disposing waste into a circular economy of making, using and returning. In the last years, the concepts of sustainable development and environmental sustainability entered in the international political agenda (Vezzoli 2018, p.3). This means that governments are being made aware of the limits of the resilience of the environment and its capacity to absorb the effects of our ways of living, the actions needed to preserve resources without compromising future generations and possible frameworks to the equal redistribution of resources among people. Since 1972 the design discipline has also started an active pathway towards sustainability. In the seventies, several theories around the selection of resources with lower environmental impact emerged. Later on, in the nineties, the whole attention moved toward the product level looking to design products with lower environmen-

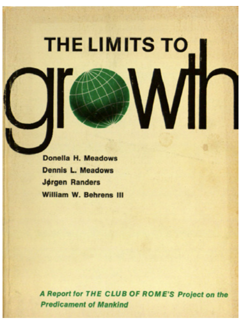
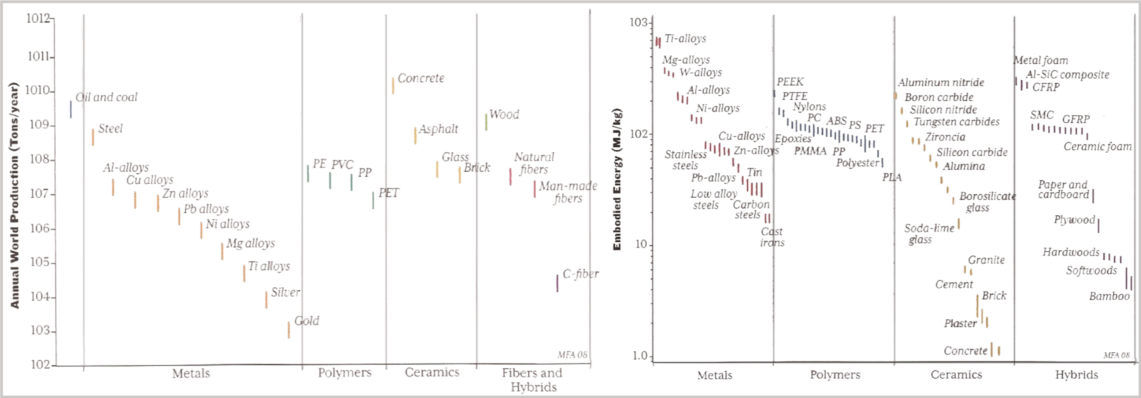


Figure 3.14
The Limits of Growth report for the club of Rome in 1972.



tal impact. In those years, the concept of life cycle was introduced. At the beginning of this century design disciplines started to focus on a more complex interpretation of environmental sustainability and began to consider a design approach of eco-efficient product-service systems. Recently, design added another layer to sustainable development by focusing on design for social equity and social cohesion (op. cit, p24). When it comes to materials, there are some considerations regarding sustainability that need special attention: the consumption of materials and the consumption of energy. The functional unit which is the unit to measure the function provided by a given product, takes into consideration the total reduction of materials, processing, transportation, distribution, use and disposal (Vezzoli & Manzini, 2008). By considering the amount of energy that is needed during the whole life cycle of a product, it is possible to understand the concept of embodied energy (Figure 3.15). Embodied energy is the one that is necessary to create a material or a product that can be recuperated in some way at the end of the cycle (Ashby, 2013). The more designers are aware of the implications of energy management, the better will be their understanding of materials and their role in sustainable development. It is possible to say that a material is considered sustainable when it has delivered higher performance with the lesser impact. Recently, the Ellen Macarthur foundation has summarized the different theories that contribute to a circular economy approach and that should be considered in design for sustainable development. Known as the schools of thought, when seeing them together is easy to understand how the circular economy principle make sense. The schools of thought for circular economy according to the foundation are: Cradle to cradle (McDonough & Braungart, 2012), performance economy (Stahel & Reday, 1981), biomimicry (Benyus, 1997), industrial

Figure 3.15
Left: Annual world production of materials.

Right: Embodied energy carried by the materials.

According to Ashby, 2009.

ecology (Frosch & Gallopoulos, 1989), natural capitalism (Hawken, Lovins & Hunter, 1999), blue economy (Pauli, 2010), and regenerative design (Lyle, 1994).

3.3.3. Social innovation definitions

In recent decades, social Innovation has become a widely used term by many scholars. Several attempts to define its nature as a field of research have been discussed in a structured and coherent way by many disciplines starting from Sociology (Howaldt & Schwarz, 2010) through Business & Economics (Nicholls, 2006) and recently Design (Manzini & Meroni, 2014).

Figure 3.16
Above: Recycled plastic bricks to build houses by Oscar Mendez.

Below: Fairphone. Modular upgradable mobile phone by Bas van Abel.

By looking at the historical analysis of macro-level Innovations across developed economies, several waves of technological change can be devised, from the industrial revolution back in the 18th century up to the age of information and telecommunication (Moulaert, 2009). In this current age of information and telecommunication technology, a new focus on types of social innovation have emerged (Hobsbawm, 1999).
There are two angles to the discussion around this area: the first one is related to the systems and processes of change in social relations. The second one is related to all innovations around the conceptualization, design and production of goods and services that address social and environmental needs and market failures (Goldenburg, et al., 2009). As those types of innovations fall into the interests of society, the definition of social innovation is grounded by nature in the social theory. For instance, innovation is "social" when it varies social action and is socially accepted and diffused (Howaldt, et al., 2015). In the words of Wolfgang Zapf (2003) Social innovations can be seen as actions that spread through the society as a result of imitation, bringing about social change. In fact, all practices known as innovations are a consequence of imitations of little inventions that a cultural group possesses, but only through the proper diffusion in different groups of the society, become visible and therefore recognizable as Innovations (Figure 3.16). Gabriel Tarde in the first half of the past century predicted that those many inventions could change society through multiple acts of imitation and as a result innovation will become an actual social phenomenon (Tarde, 2009).
What is becoming more visible nowadays and is relevant for the Social Innovation theory and this research, is the growing need to create

innovations from the micro level of the society which can spread on a larger scale to become socially accepted and diffused. As the Vienna Declaration suggested in 2011, the most crucial and important innovations in the 21st century will take place in the social field (Franz, et al., 2012).

3.3.4. Creative Communities

In the year 2006, a group of scholars led by Ezio Manzini conducted a research called Emerging Users Demands for Sustainable Solutions (EMUDE). This study revealed the existence of a dynamic form of creativity called "diffuse creativity". This kind of creativity appears in a co-operative environment of non-specialized people seeking for a particular solution. The EMUDE research also highlighted that this enterprise of individuals who act together seeking a particular solution of any problem inside their environment is recognizable as a "creative community". Creative communities are groups of people who invent sustainable ways of living (Manzini, et al., 2008).

Although creative communities are very diverse in their nature and in the ways that they operate, they act as original innovators in their local systems. These communities often challenge traditional ways of doing things introducing radical solutions (op. cit). Amplifying the definition of Atkinson of DIY practices (Atkinson, 2006), it is possible to say that the community operates in the more democratic process of collectively-driven and collectively-directed method akin to that of an amateur design and production activity carried out by the end user. This community can act as DIYers of things, mainly as everything they create often is a solution for them to use. These communities share another interesting feature: within them exist individuals endowed with unique design skills who can set, translate or introduce tools and methodologies that guide the process. Just like the DIY subculture, these communities can do things that work better than the traditional infrastructure of the society (Lukens, 2013). They don't even expect to create general changes in the system they belong to (such as institutions and large infrastructures of the society that control energy, agriculture, banking and finance, water supply, public health and critical manufacturing), they just want to improve the current state of things producing something different.

Another important consideration highlighted in the EMUDE research about creative communities is the fact that they are deeply rooted in a place, they make good use of the local resources, and directly or indirectly they promote new ways of social exchange (Manzini, et al., 2008). Similar to the Maker's movement, they are globally linked to similar communities. This network enables experience and problem sharing, which in turn, allow a high chance to create innovative and sustainable solutions easy to spread around. For the DIY-Materials this is a key element to consider as this communities make good use of resources and share social wellness. This will give DIY-Materials an opportunity to act.

3.4. Discussion

In all the concepts described above, the necessity of the people from different fields of knowledge to tackle the challenges of modern societies is visible. There is, today, an urgent call not to change the course of what humans have created during the evolution of the race, but to offer alternative paths, different visions and propose evidence to support those paths and ideas to make them viable. This research on alternative materials development opens up new possible scenarios. As mentioned in the beginning of the chapter, it is difficult to talk about materials outside the closed cycle of materials science and engineering. It is essential to mention that before the first wave of technological change, known as the industrial revolution, the materials domain was in the hands of artisans, and their knowledge was diffused and connected. During the 18th century, a bifurcation occurred between organized industrial processes guided by control and accuracy on one side, and the free and semi-accurate processes of traditional crafts on the other (Atkinson, 2006). In that sense, nothing new is proposed. Yet, right now there exists an opportunity for people to see alternative ways to transform materials as the triggers of change. The possibility of communities to re-evaluate at their local resources, experiment with them and find creative solutions to tackle their wicked problems guided by methodologies to deal with materials is a great challenge. However, there is a fabulous opportunity for those communities to succeed by becoming materials activists. Once a local open sourced technology is controlled in a co-operative environment of non-specialized people and based on a sustainable way to deal with materials, the products and services that emerge will become a fertile ground for social business to follow. This business will allow the maintenance of the local economy.

With this, the definition of DIY-Materials becomes richer as it sees

materials as ideas that simultaneously meet social needs and create new social relationships or collaborations. In other words, they can be innovations that are both good for society and enhance society's capacity to act and build social businesses.
It is worth noting that this dissertation does not contain significant studies on the social aspect. This research aimed to highlight above all, the possibilities that DIY-Materials could provide in the future. Chapter nine will explain the possible streams for this theory to disseminate. This whole theoretical framework made from different literature reviews and approaches from various fields can be used in future studies to improve results and theories proposed in this dissertation.
The next chapter will present the main studies conducted through this doctoral research divided along exploratory studies and test studies.
The three macro areas of research described above and the intersections among them were strongly considered throughout the studies.

Chapter Four

Pre-Study: Categorization of DIY-Materials

Each theoretical background group from the previous chapters contains several literature reviews on its domain and can be seen as an individual element. Nevertheless, for this Ph.D. dissertation, the interconnections of the three macro areas and their particularities are the focus, as is in the interconnection and relationships where the DIY-Materials phenomenon can be better understood. This chapter focuses on the identification and analysis of the different cases of DIY-Materials created by designers and their possible relationships. Familiar methods like case studies and design ethnography have been applied as well as tailor-made instruments. The analysis of the different relations of these cases make it possible to propose a categorization for the different categories of DIY-Materials into Kingdoms. By using the proposed taxonomy, it is possible to better understand each case and identify patterns to guide designers in the development of a DIY-Material, as is explained in more detail in **chapter five**.

There is a degree of complexity in connecting materials science with autarchy practices and sustainability related issues. Initially, it may seem that the three elements have no connection at all. Material sciences are exact in the methods they utilize, the formulations for each step are mandatory and nothing is left adrift (Figure 4.1 a). Autarchy practices like DIY, on the other hand, tend to be more loose, as one explores different random possibilities in the research for the autonomy of resources (Figure 4.1 b). Finally, sustainability related issues are broad and difficult to classify. Understanding the different cultures and ecosystems on the planet to be able to solve a particular problem requires time. It is crucial to spend time living in a specific region and amongst a group of the population to better learn how to act. As mentioned before, seemingly the three elements have little in common and there may be no need to match them. However, when studying different cases of different designers who embarked on a material based project, or a DIY-Material project, some insights become visible. When they decide to tackle a particular problem, and choose to experiment by understanding the raw material they intend to work with, the scientific knowledge they start to obtain and the impact this project starts having in a particular place or group in the society, the hidden connections of the three elements begin to emerge.

4.1. Categorization to bring order to a scientific endeavor

For this doctoral research, it is crucial to understand all the different initiatives designers have or have tried in order to gain autonomy in the development of materials. In the previous study by Rognoli et al. (2015), where DIY-Materials found their definition, some cases were highlighted and divided into two main groups: DIY new materials and DIY new identities for conventional materials. It was reasonable to split the cases into those categories; however, with the growth in the number of cases - as in the past two years from the publishing date of the article until the conclusion of this chapter - there was the need for a more in-depth categorization. This categorization does not intend to override the previous one, in fact, understanding which ones are new materials developments and which others are reinterpretations adds enormous value to the new taxonomy. The problem was that too many cases with different ingredients, motivations and experimentation tracks could not highlight a pattern to prove the hypotheses that DIY-Materials held the possibility to become more than a trend. Also, the previous categorization does not emphasize or allow to see the interconnections between the theoretical background groups mentioned above, (and explained before), is where the DIY-Materials tend to express more of their value.

For this new categorization, the selection of two methods to understand why designers have embarked on this way of creating materials instead of selecting existing ones and most importantly, how they do it, were of great help. The first one known as Cases Studies (Stake, 2000), helped to create a proper categorization of Do-It-Yourself Materials by conducting an in-depth examination of the different cases highlighting different common elements between them. The second one is known as Secondary Research (Booth et al. 2008 p. 76) and it allowed the analysis of the different cases inside each kingdom grasping qualitative data of each material and is explained in **chapter five**.

a.

b.

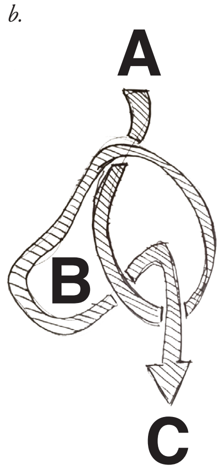


Figure 4.1
(a). Science methods, formulations and workflow.
(b). DIY methods, experimentations and project definition.

4.2. Case Studies of the DIY-Materials

A handy definition of the case study strategy is the one provided by Yin (1989): "A case study is an empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used" (p. 23). As Yin and others point out, case studies often use quantitative measures. Despite this, when this strategy is applied to the DIY-Materials phenomenon, a more qualitative perspective tends to appear and it becomes easier to understand the event from the materials experience point of view. All selected cases reflect the experiences the designers had while developing the material as well as the intended outcomes they tend to elicit in the users in the applications of those materials (Karana, Pedegley & Rognoli, 2014 p.XIX).

The study of different cases was crucial to encounter some findings to validate the following hypothesis: Anybody with knowledge on crafts can embark on a materials development. As it is known already from the DIY-Materials definition (Rognoli et al., 2015), those materials emerge "through individual or collective self-production experiences, often by techniques and processes of the designer's invention, as a result of a process of tinkering with materials" (p.2). Indeed, those techniques and processes cannot occur if the designer is not trained to do things with the hands. It seems obvious but is essential also to underline that contemporary designers may not always be prepared to do something physical as they used to before, or at least are not obliged to do it. With some new variations in the profession, like Business design, Service design or even Experience design, some designers do not gain in-depth knowledge on crafts but gain some expertise in user experience, human-centered methodologies and paper prototyping.

In his book, sketching user experiences, Bill Buxton highlights different techniques allowing designers to sketch and prototype with tools in hand like paper or cardboard (p. 371). These tools together with CAD software are powerful tools that allow designers to generate visual storytelling for the proposed project (p.277), without requiring a master in the crafts and manipulation of a material or a particular technique.

The reader will see in the different case studies and in their analysis in **chapter five**, how crucial the mastery of crafts is to achieving a DIY-Material. Despite that, it is worth also underlying that designers, when they gain skill in both conceptual and crafts tools and techniques, can achieve even better results when it comes to materials development. Designers with the capabilities to manage visual storytelling techniques tend to provide a better description of the whole process and are confident in highlighting essential elements of their discoveries. By doing so, the materials samples embed an emotional content that the designer transmits when presenting the material.

4.3. Unsorted Collection of Cases

A total of 145 case studies from different sources, mainly media (Internet, Books, Magazines) have been studied. Some cases reported in their descriptions valuable information such as the ingredients or sources composing the sample. Some others were more vague about the story, pointing out just a critical element that forms the material. Naturally, some designers want to keep a level of secrecy of the formulation to protect their intellectual property of the material. On the contrary, others based their material on traditional recipes or collected data from an open source material development previously published by a DIY enthusiast and built up their project in a collective learning way of designing. As some of the cases lack crucial information or relevant data to allow a proper triangulation of information the full analysis of case studies was limited to one hundred.

4.3.1. Pre-classification

As explained by Ashby and Johnson (2002), "classification is the first step in bringing order into any scientific endeavour. The founders of biology, zoology, and geology were those who created the classification systems. Classification segregates an initially disordered population into groups that in some way have significant similarities (p.117).

The one hundred cases which passed the initial filter, respond to different questions and allowed data collection for a full classification (Figure 5.1 on **chapter five**). If a DIY-Material or its designers show the process of obtaining the material, (even if they omit some crucial information as mentioned above for IP protection) then, they are worth analysing. One of the hidden findings that almost all the selected cases had in common has to deal with the way of telling the story. From simple one angle camera focusing on the workshop table while

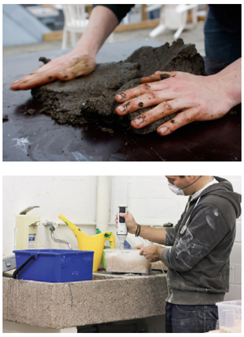


Figure 4.2
Typical layout of DIY-Materials. Photos by Edvard and Aumer.

Figure 4.3
Elaborated movies and photography's to tell the story. Photos by Swine and Visser.

the designer "cooks" the material (Figure 4.2) typical layout of the DIY subculture, to the award-winning movies that are elaborately put together by filmmakers and photographers (Figure 4.3). All designers want to tell a story. This insight is a crucial element of the DIY-Materials theory building, as it shows a particular pattern where design thinking plays an important role. All designers know that one of the primary goals as professionals is to communicate either graphically or through physical objects the desired intentions or the experiences people may have with their creations. Different from material scientists, designers spend quite some time explaining the whole process. It is a standard requirement in all art and design schools to learn how to show the highlights of a particular project, a reason why many designers spend the last nights before the delivery of a project finalizing not only the prototypes but organizing some boards or videos to make things clear. This feature that is also visible in the different cases studied.

4.4. Classification of the DIY-Materials: The Kingdoms.

The categorization phase began by analysing the one hundred best and complete cases of DIY-Materials found in all different sources of media available. The first insight came after seeing over and over how important was for designers to highlight the sources used for their projects as starting material. It is of great importance based on the fact that different from traditional materials, where it is a certainty that plastic comes from petroleum and glass comes from silica, the origins of DIY-Materials are not always so evident. Once the first screening and analysis concluded, the possibility to organize them into groups of items based on similar sources became clear. The material sources were divided into five main families sharing similarities. A second insight appears when more cases begin populating each family. The three first families share a clear analogy to the biological classification of natural elements. Attracted by such encounters, the necessity to find the primary biological classifications of history took on extreme importance. Such search landed into the work of the Swedish botanist, zoologist and physician Carolus Linnaeus called Systema Naturae (Linnaeus, 1740). In his first edition, Linnaeus published, what became for several years, the standard biological classification of the elements of earth. Known as Linnaean taxonomy (Figure 4.4), this landmark publication established a hierarchical classification

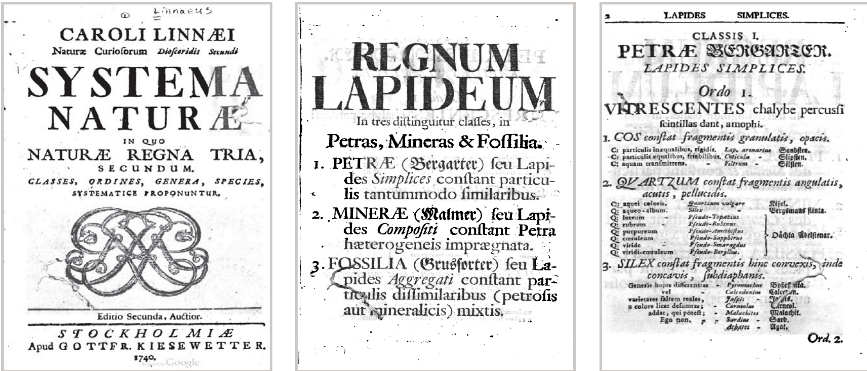


Figure 4.4
Original publication of Linneaus with the kingdoms of nature.

of the natural world, dividing it into three main kingdoms: animal, plant and mineral. Although the modern biological nomenclature has evolved into several more profound divisions of nature`s taxonomy, the original one provided by Linnaeus, provided to the classification of the phenomena a remarkable and delightful source for naming the categories.
Apart from the first three categories another two families of cases were formed also based on their primary sources. They were particularly challenging to name as the first populates with cases dealing with waste and the second was connected either with information technologies or manufacturing techniques.

The connection with the Linnean taxonomy is fascinating and worth being inspired by The new DIY-Materials categories which hereafter are named kingdoms (Figure 4.5). The kingdoms obey mainly to the source of matter or ingredients that allow the development of the category to create a particular material. Each kingdom is subcategorized as well according to the similarities some materials inside the kingdom commonly share.

This study builds upon the theoretical background explained in **chapter three**, and it was presented in 2017 in the Eksig 17: Alive. Active. Adaptive. International Conference on Experiential Knowledge and Emerging Materials, Rotterdam-The Netherlands with the title: Five Kingdoms of DIY-Materials for Design. (Ayala-Garcia, Rognoli, & Karana, 2017). This chapter contains extracts from the presentation and is extended and enriched with some in-depth description of each category and subcategory. In each subcategory, the different cases are embedded for better reading and as is mentioned above, storytelling tends to provide a better description of the whole process of a materi-

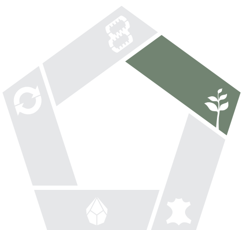
Figure 4.5
New Kingdoms emerged in the classification as a result of contemporary human impact.

al. However, in **chapter five** it will be possible to see the whole list of the one hundred cases in the categories where they belong.

Figure 4.6
Codes for Kingdom categorization.

The order of this categorization and subcategorization may not correspond to the order in the charts. This happens because the cases were assigned a code for the different instruments in order of appearance and moved to each kingdom afterwards (Figure 4.6). The different cases with assigned codes appear in the appendix.

4.4.1. Kingdom Vegetabile



Refers to every material development where the primary source for a DIY-Material derives from plants and fungi, (maintaining the original Linnaean taxonomy where “fungi” belong to the XXIV Class Cryptogamia)[1].
Materials under this kingdom differ from the others, mainly because they can be derived from growing or farming techniques. Designers who create materials under this category collaborate with, for example, farmers and biologists.

When thinking about natural materials, the brain connects many of these materials with crafts. common materials which emerge in this thought are wood, cotton or silk. In people’s minds, the idea of natural materials has something to do with someone doing something with their hands. This maybe the fault of industrialization. When humans started engineering materials, they began to think about a natural and an artificial division between materials. The natural ones are often perceived as materials of small scales while the artificial ones appear to be produced in large amounts every day by non-stop factories in some corner of the world. It is an apparent misconception, as modern societies are transforming natural materials into more extensive and scary quantities. Hopefully DIY-Materials may create some balance as there is an emerging awareness around the issue, and not everything can be scalable.

1. In Linnaean taxonomy, the classes and orders of plants, according to his Systema Sexuale, were never intended to represent natural groups. Classis XXIV. Cryptogamia included the “flowerless” plants such as ferns, fungi, algae, and bryophytes.

However, the word "natural" is an arguable concept depending on the field of research, the type of subject or even the application. Depending on the context, all materials can be considered natural. In the eyes of the designer, however, the natural materials deal with something that is grown or farmed. Natural elements have a poetic quality to them and when designers think about a natural material, they also think about the qualities these materials express. Patterns that fibers and knots on the wood highlight, or the touch of a particular fiber that feels right on the body, are qualities a designer is keen to explore, above the durability or manufacturability of a material sample.

The concept of natural also evokes the idea of life and death. What comes from the earth should go back into it. A material considered natural is often qualified as a material which has a short lifespan before it returns to earth. This idea is more suitable for designers than for engineers or material scientists. The idea that something gets rotten, breaks, loses colour or even falls apart must be avoided at all cost in engineering and long scale manufacturing terms. Some designers on the other hand believe that this specific behavior of a natural material has its advantages (Saito, 2007; Van Hinte, 1997). For instance, If the project considers those qualities probably the final application of that particular material will be intended to live compact and as a whole, as long as the material allows it.

Kingdom Vegetabile is divided into: farmed materials, wild findings, materials that grow, pieces of food, and cover skins, peels and natural packages.

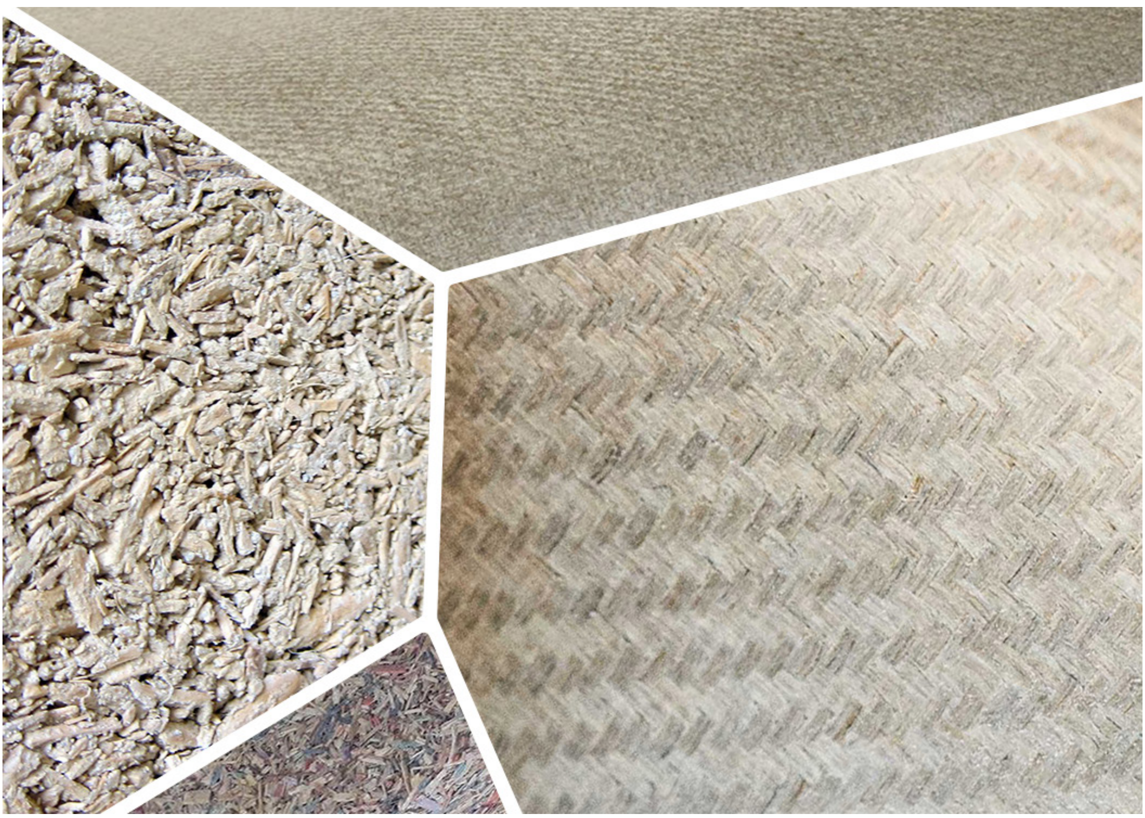
Farmed Materials

Several types of materials have been extracted since the beginning of the agricultural revolution (Harari, 2015). For thousands of years, humans have been able not only to grow food but also to farm some materials to build civilizations. Some ancestors raised cotton or hemp for clothing; some others collected palm tree leaves to repair from the sun and so on. In this rediscovery of the biodiversity of the planet through the eyes of the designers, a great perspective emerges for multiple purposes and projects. In this new generation of craftspeople, empowerment of digital tools has increased the pace of collective learning (Gauntlett, 2011). All over the world, it is possible to seek (not even invent) techniques coming from ancient knowledge which by different motivations, (probably by the complexity to upscale production) were forgotten by the modern world. These techniques appear back with the possibility to reshape objects and products that are misconceived by industrial processes and materials, mainly because of their life cycles. These new generations of designers have learned over the past two decades and throughout the globe, that the once valid theory of one material-fits-all, is not only unsustainable but also undesirable.

2. CES Edupack Database and Nike MSI Index.

Flax, according to different databases[2] is a material that with high resistance to wear and abrasion. It is a breathable fiber and absorbs humidity quite well. From the qualitative side, flax is also a friendly material capable of maintaining its structure while being light and soft. Some evidence has shown that in the northern parts of Europe, the use of flax started in the upper Paleolithic period (Balter, 2009). Considered also to be a significant source for linen industry in Europe in the middle ages, it lost its importance to the industrialized eye in comparison to more durable fibers. However, in the northern parts of Europe it is still considered of great value and is widely used in the creation of ropes and other similar products. From that region, it is

Figure 4.7
From top right, clockwise (a-b) Flax Project by Chiristien Meindertsma. (c-d) Hempcrete by Studio Green.



possible to find the work of a designer called Christien Meindertsma (Figures 4.7 a - b).

Meindertsma developed a project called flax project. In this project, she embarked on a quest that started from planting the seeds and went through the entire process of harvesting the plant. She obtained a material that allowed her to develop a series of products with particular physical and qualitative characteristics, such as lightweight, strength, as well as visually textured, with a warm and informal look. What is relevant about this project is the concept of the designer who understands the whole process of the harvesting of material, and thanks to that gained knowledge, the further operations of tinkering with the material allowed her to produce unique products with their particular language.

As mentioned before, hemp is used for thousands of years to build ropes, clothes, paper and textiles. Different countries around the globe have found ways to industrialize the production of hemp as well as farm it properly for industrial purposes. Hemp is a very controversial crop, as it is known to derive from the cannabis sativa plant species. The overall misconception surrounding the industrial hemp is the tendency to compare it with its cousin species, capable of producing psychoactive effects. The main differences between the industrial "legal" hemp and its counterpart, has to do with the amount of TCP or tetrahydrocannabinol available on each plant (Keller, 2013). While in the industrial one the levels are low and, therefore, has no effects on human behavior, with the other, the results are stronger in human bodies and are subject of discussions of various kinds (p.556). Regarding our research on DIY-Materials, it is known that since the year 2008 a particular mixture of the inner hemp stalks with limestone and water to produce a kind of brick known as Hempcrete. The material is open sourced, and nobody has claimed authorship of it. However, many architects and designers are starting to use it for different projects[3] (Figures 4.7 c – d). One studio from Singapore is working on it in depth as a material development. This case has been published in a complete DIY-Materials process, typical from the case studies. The studio is called studio green. It is important to highlight about this case study the capability of a DIY-Material to be scaled into industrial production.

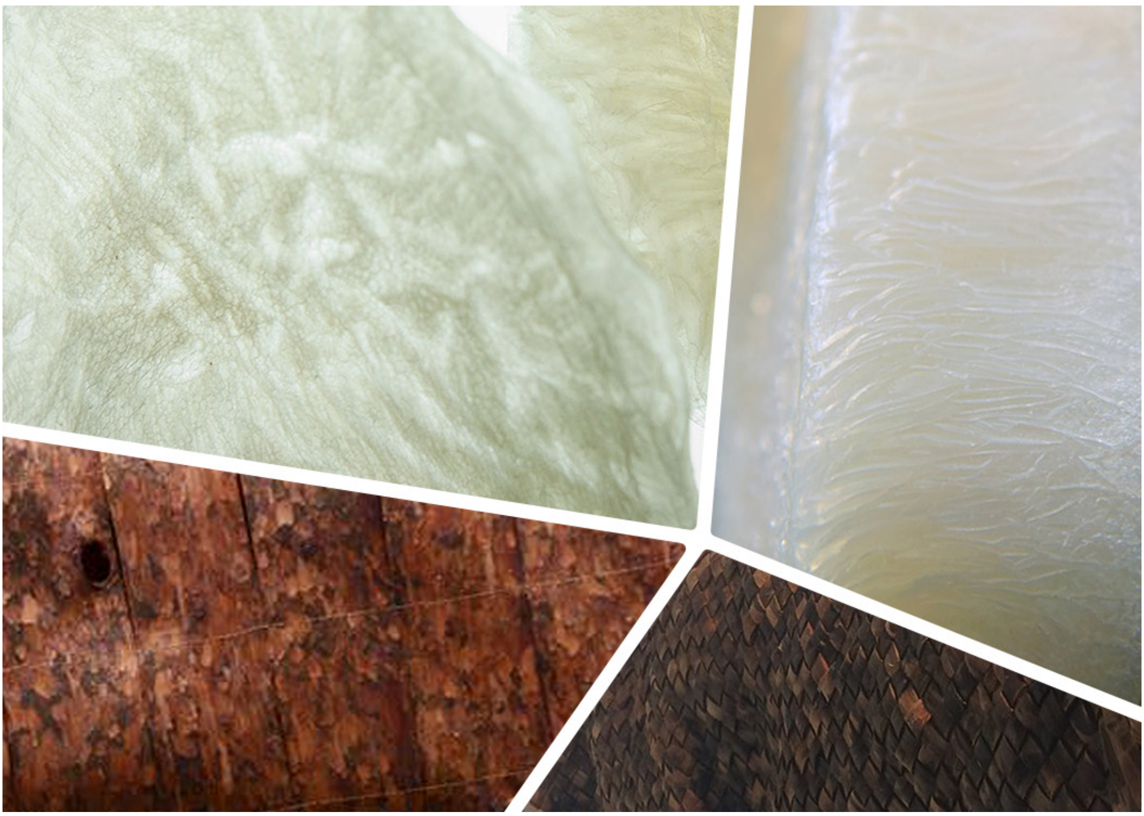
3. See the work of the TAV Group studio based in Israel; The work of the architect Martens Van Caimere from Belgium and the work of Mikhail Riches Architects based in the UK with Hempcrete Material.

Wild Findings

Some materials can be obtained from ancient farming techniques, some other materials can be created by gathering wild sources. Wild sources mean the ones not obtained from traditional harvesting, but gathered elsewhere. Some of them are well known in a particular cultural environment, and should remain like that. These sources are also sometimes abandoned by the global industrialized perspective, as they do not represent a scalable resource. It is possible to find these valuable sources for materials in the dense trees of the northern hemisphere or in the lakes or the sea. Here, again it is essential to see how the designer's trained eye can find them and with the desire for experimenting and crafting, original results emerge.

Sarmīte Poļakova, a Latvian designer, developed for her Master's dissertation project at the Design Academy Eindhoven, a project called "A story about a pine tree" (Figures 4.8 a - b). In this project, she makes an interesting reflection. In Latvia, there are five hundred times more pine trees than people living in the country. since ancient times the pine trees are a source of food, medicine or magic. Currently, the

Figure 4.8
From bottom right, clockwise (a-b) A Story About a Pine Tree by Sarmīte Poļakova. (c-d) Agar Plasticity by Studio AMAM.



only value of those trees in technical terms relies on the capacity to become softwood. By doing so the rest of the tree is discarded. The designer proposes a material created from the inner bark of the Pine which has leather-like properties, natural color in volume, and elegant and strong character. This soft material with a lifespan of up to two years is an excellent surrogate for materials in products with such life-cycle. Once the time for the use of the product is over, it can return to the earth to begin its next story.

Different coastal cultures around southeast Asia have used macro algae for food purposes since the sixteenth century. The extraction of alginates, as well as agar and other gelatinous substances, are critical for the food industry (Hopley, 2010 p.31). Agar Plasticity, it is an on-going development by the Japanese Studio AMAM (Figures 4.8 c - d) Inspired by the Japanese tradition to produce sweets, the material developed comes from seaweed with a mix of agar, obtained by boiling red algae. It comes in powder, sheets and block formats with different thickness and hardness that allows creating any desired shape. The result is a translucent, bumpy flexible material with the capability to replace different plastic-made products. The designers state that the plasticity of agar can be taken further with the aid of other disciplines.

Materials That Grow

Grow is something often seen in people's life but most of the time not considered as a materials approach. Often leaving something abandoned in a place, when is rediscovered becomes covered by different elements that have grown around it. Sometimes these elements may not be perceived as pleasant. Science and sometimes science fiction has shown us fungi and bacteria can be hazardous to human beings. If someone sees fungi growing over an element, they tend to react fearlessly and with disgust to it, often believing that these particular fungi will continue to grow over everything else around. That is not particularly untrue, and as many biologists suggest, humans have specific incompatibility to the world of fungi and direct contact must be avoided to prevent harm and health problems[4]. However, some mycelium is known to be harmless and can be understood regarding its growth, as it can take different shapes and forms. Paul Stamets (2005) published a book called "Mycelium Running: How can mycelium save the world". This publication is probably the first time where the benefits of this material were highlighted outside therapeutic uses.

4. According to De Lucca (2007), most fungi are not pathogenic to plants, animals and humans. However, a relative few fungal species are phytopathogenic, cause disease in man.

Figure 4.9
From top right, clockwise (a) Grow it Yourself by Ecovative. (b) The Growing Lab by Officina Corpuscoli. (c) Algaemy by Blond and Bieber Studio.

The first ones to explore these qualities from a design perspective were the founders of Ecovative Even Bayer and Gavin McIntyre in the United States (Figure 4.9 a). Once they graduated, the couple decided to push a series of experiments into a venture that is now the leader of Mycellium composite formulations. Free from spores and mold, the Mycelium materials are proven to be safe for human use and the process to produce them is quite entertaining and straightforward. Mycelium is considered the fast-growing, vegetative part of fungi. It's formed by a compact network of filamentous cells, called hyphae. Because of this structure, the mycelium harvest, transform and distribute nutrients, both for its benefit which causes the mushroom to grow, and to provide health to the ecosystem as well. The Mycelia tend to grow on a wide variety of substrates allowing to convert agricultural waste into natural compounds for human use.
An Italian designer called Maurizio Montalti (Figure 4.9 b), together with a team of experts devoted some years of their work to better understand this particular material in a project called "The Growing Lab." By acknowledging that its growth can be controlled, and at a specific moment, stopped, new landscapes for products are emerging.

Other materials that grow and humans can control for different purposes are the microalgae. The textile designer Essi Johanna Glomb and the product designer Rasa Weber from Germany (Figure 4.9 c) reveal in a project called Algaemy the aesthetic potential of this particular resource. By developing a DIY machine with an alchemist look, the designers were able to extract different pigments with a specific palette of colour, to print textiles in what they call an autarchic circle of production, which does not require additional energy or material apart from human power and the microalgae itself.

Pieces of Food

Dealing with food is a sensitive subject. One cannot jeopardize the means of sustain of a community. Doing something physical for use when the material utilized is better to feed humans can raise some ethical problems. As certain as it undoubtedly is, it is worth also saying that some of the elements used to feed people like sugar, are not only mandatory on diet but also harmful to big groups of the population by the excessive consumption. Sugar, for instance, reached a peak of 180 million metric tons of world consumption in 2017 and is used in

Figure 4.10
Top and bottom (a-c) Sugar Glass by Fernando Laposse.
Right and Left (b-d) and Shaping Sugar by Amelia Desnoyers.

unmeasured scales on the products people eat[5]. Walk around a supermarket and pick any product on the shelf for breakfast or your kid's meal and read the nutrition facts table on the packaging. You will be amazed by the amount of sugar included in the product.
Fernando Laposse from Mexico (Figures 4.10 a - b) and Amelia Desnoyers from France (Figures 4.10 c - d), are two designers who take advantage of the process of sugar glazing. An old tradition in the patisserie industry is readily replicable to learn production techniques such as rotational molding. Both designers create a collection of edible tableware using sugar as their main constituent. Despite the designed product, the power of the project does not rely on the glasses and their attributes, but in the DIY machinery the designers have built to produce the desired shape. When designers gain knowledge from the food industry or learn from chefs and bakers their techniques to shape and decorate food, they start connecting those techniques with the industrial processes of higher scale. All the methods industry uses may have a way to be explained with less sophisticated tools like the ones the kitchen provides (Ayala-Garcia, 2015).

5. USDA – Sugar World Markets and Trends report 2017.

Cover Skins, Peels and Natural Packages

One of many concerns, when dealing with materials sources, is as mentioned above, the risk of using food elements that are needed for human sustenance. Many fruits and vegetables are rich sources to maintain lives and, therefore, it may be considered unethical to use them for other purposes. However, many of those fruits and vegetables when farmed in more significant quantities represent a problem as they are discarded in substantial amounts (Porter et al., 2018). here There may be an opportunity for material development. Many fruits and vegetables are naturally packaged and have great potential to replace commodity polymers or other harmful materials used for disposable applications. Many designers have found that this type of materials can be considered surrogates for plastic or leather in different forms and are pushing for new social economies through the use of these materials.

Designer Spyros Kizis from Greece (Figures 4.11 a - b) is taking wild artichoke thistle, a common resource in the Mediterranean diet for many centuries, to develop a particular material. Mixing the fibers of the thistle with a bio-resin, the designer was able to create what Blaine Brownell[6] calls a "plant fiber–reinforced plastic." Using the same tech-

6. http://transmaterial.net/artichair/

niques and production methods for the transformation of glass fiber reinforced polymers, Kizis is producing a material that looks Aggressive and Extravagant but with high levels of biodegradability. Different from GFRP, this material when buried, can potentially transform into new plants, as the designer intentionally spread inside the composite artichoke thistle seeds.

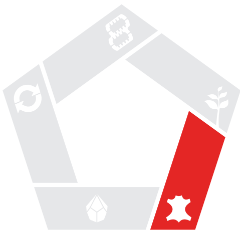
Figure 4.11
From bottom right, clockwise (a-b) Artichair by Spyros Kizis. (c-d) Piñatex by Carmen Hijosa.

Piñatex is another example of how a byproduct of a particular plant can become a surrogate of a material, in this case of leather. Carmen Hijosa (Figures 4.11 c - d), a Spanish designer, spent several years in the Philippines. In the Islands, she realized that the strength and the fineness of the pineapple leaf fibers used in the Barong Tagalog, a type of formal shirt considered the national dress of that country, could make a non-woven mesh from the long fibers. With a similar leather-like appearance, with a classic look and particular tactile experience, this material can be dyed, printed, and treated to resemble leather without the harmful treatments of tanning.

7. https://www.cartier-womensinitiative.com/candidate/carmen-hijosa

“The average pineapple plant has between 30 and 40 leaves around it, each about one meter in length. To produce one square meter of medium weight Piñatex, 480 leaves are needed – or the byproduct of 16 pineapples, of which there is a crop every 14 months"[7].

4.4.2. Kingdom Animale



Refers to all material sources derived from animals and bacteria. Note that bacteria were unknown when the Linnaean taxonomy appeared, but due to its behavior as a living organism, is possible to insert it into this kingdom. Those materials can be developed either by collaborating with living organisms or by using parts of the animals, like hair or bones.

Animals have been a topic of debate in recent years as some species the humans breed are achieving some levels of overproduction with the need for strong chemicals as well as non-suitable places to grow[8]. These conditions have raised some awareness about human's role in the food chain and the critical role some animals represent in our diet. Some other studies defend theories around the importance of this human-animal relationship regarding food as it is possible that our specie owes part of the evolution to this matter (Pobiner, 2013). As designers, it is possible to be active participants in the debate but without entering in depth as it is an issue to be addressed by many different disciplines, cultural beliefs and governmental policies. From the perspective of the development of materials, three main streams are visible. In the first stream, it is possible to find several attempts to create with the aid of animals. it is interesting to see materials developed co-creating with living organisms such as bacteria, worms, bees and ants.

8. according to Idemat database LCA Food Database http://www.ecocostsvalue.com/EVR/model/theory/subject/5-data.html

On the second stream, it is interesting to see how designers understand how several elements coming from animals after they passed away, either by natural or induced ways, can be repurposed as materials for projects. In this stream it is essential to underline that in several cases, designers are aware that elements such as bones, nails, gutters, or even part of their skin, are used for hundreds of years by different civilizations in an attempt to build their environments, prior to the advent of industrial engineered materials.

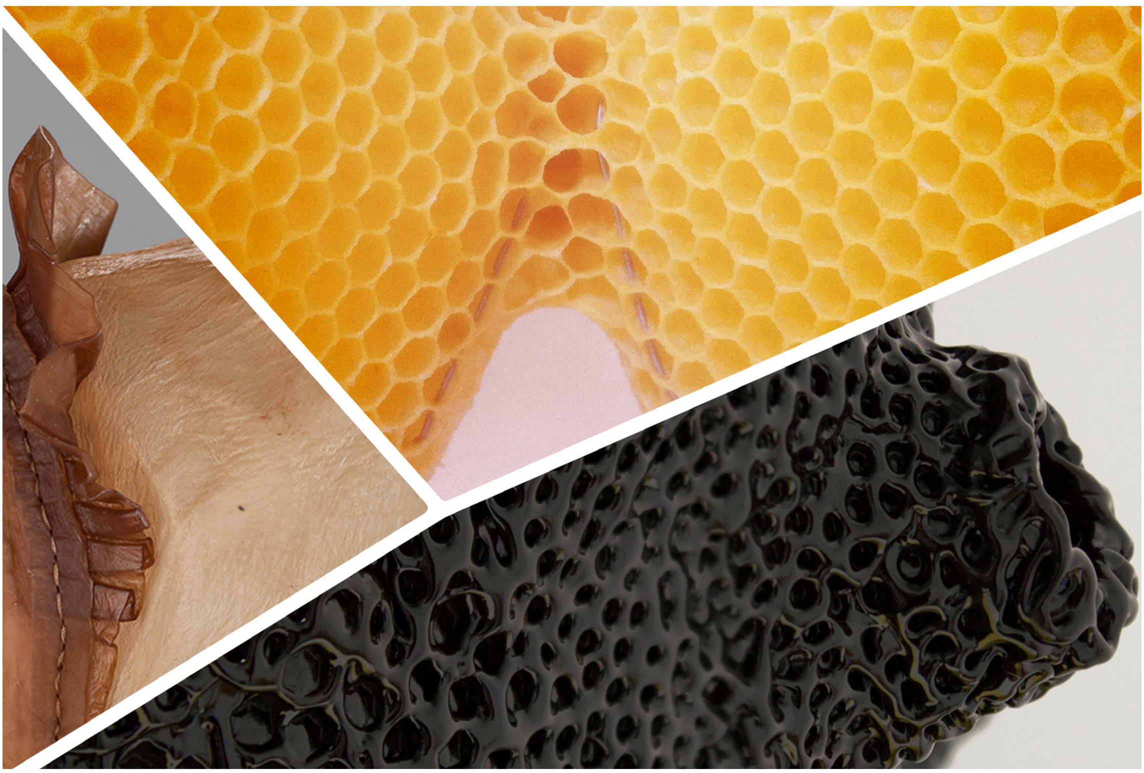
The last stream is more related to the different elements that are produced by animals. In this particular one, even humans are considered part of the group. Taking elements like hair or nails which grow continuously and by treating them appropriately, can become an excellent source to build stuff. It is not only something our ancestors did for centuries, but something which nowadays can represent a balancing element to contrast petroleum-based materials that are misused in some applications.

Kingdom Animale is divided into: co-creating with animals, animal remains, and animal production.

Co-Creating with Animals

Some living organisms work on a daily basis as part of their way of living. Bees, ants, worms and spiders are some examples of animals devoted to constructing elements day by day to assure their subsistence. Some designers have been analysing their behavior, and without interfering in the biological means that those behaviours represent fur the sustenance of a particular species, have started a process of co-creation. Sometimes animals with proper guidance can create fantastic elements, which when they do not need them anymore, can become useful for the human beings.

Figure 4.12
From top right, clockwise (a) Made by Bees by Tomas Libertiny. (b) From Insects by Marlene Huissod. (c) Biocouture by Susan Lee.



Made by Bees is a project developed by Tomas Libertiny (Figure 4.12 a) in which a conscious study and collaboration with bees allows him to understand how to create physical elements with a unique honeycombed surface. In a process, he calls "slow prototyping" four thousand bees work during a week to produce a shape over a honeycomb structure. Marlene Huissod, being raised by a bee's farmer, has been attached to them as well. This is of particular importance in the design field, as emotional attachment sometimes can help derive specific solutions that the structured ways of thinking from the classical sciences will never achieve. In her project From Insects (Figure 4.12 b), the designer extracts the propolis bio resin from the beehive, carefully heat it in a blowing-glass kind of technique, and sculpting different shapes and textures.

Bacteria is one of the biggest group of living organisms found to date. Consider the possibilities that these organisms can represent to human life apart from the ones that are deemed harmful to our environment and new opportunities emerge. Understanding the potential some of them serve, it can be of enormous advantage also to contrast human impact on the planet. Susan Lee is probably the designer who has broader knowledge around creating materials out of bacteria. Lee began research around fashioning the future, and by meeting with biologists, she realized the potential to use bacteria to grow a material in a project called Biocouture (Figures 4.12 c). Bio couture is a material made out of a symbiotic mix of yeast and bacteria. It's a fermentation method that grows bacterial cellulose inside a container. Once clean and dried, it is processed like a regular piece of fabric. Later, she started - a collective together with some biologists called bio-fabricate with the aim of researching methods and ways to produce synthetic biology materials with the aid of biotechnology. It is an excellent example to highlight in the DIY-Materials domain, as it is one of the projects which started as a designers' experimental research project, then inspired science and technology and currently is being scaled as an industrial material called Zoa. It is one of the possible directions a DIY-Material can take and is explained in **chapter nine**.

Animal Remains

Life and death is a sensitive subject to address from a material's point of view. It is a current issue that human population has grown unmeasured in the last century and the meanings of sustaining our subsistence are jeopardizing other species and the planet. The landmark publication, the limits of growth (Meadows et al., 1972) predicted how an uncontrolled increase of population and production could lead to a catastrophic future (p.45). Forty-five years later these theories are proving to be correct and the call to action is crucial. The animal's humans eat together with the animals who help in the processes of agricultural farming could be of great help in the change of perspective from overproduction and over-consumption. Tons of animal carcass and shells are discarded after extracting their nutrients for human sustain. Such mass is beginning to weigh negatively in the public health of major cities. Many different solutions are being discussed, starting from the idea of consuming less meat to the diversification of human diet. Despite this, another solution is being addressed by designers by using those animal remains creatively.

Hidden Beauty is a project of Eva Schlechte and Jennifer Hier from Germany (Figure 4.13 a). The designers take advantage of an old tradition of the German culture, where inner skins from sheep, pigs and cows, were utilized for a wide range of applications. Animal entrails like bladders and intestines could be used as a material for different short-term purposes and the designers are proving the aesthetic potential of such materials. Sometimes undesired and sometimes repulsively treated with disgust, these materials can be of great help if when considering the possibilities that they can provide to reduce the usage of synthetic polymers in the food industry. This type of initiatives could push scientific research to encounter ways of proper cleaning and sanitizing naturally such materials to tune up production alternatives to replace plastic.

Aagje Hoekstra from the Netherlands proposed a project named Coleoptera (Figure 4.13 b). The material is made out of pressed insect shells. Mealworm beetle is a particular insect commonly used and bred for the animal food industries in their larvae state. Once it is dead after completing its natural life cycle, the shell is left without any other use. The shell itself contains Chitin which is a very common natural polymer, that is furthermore pressed with the remaining parts of the animal to obtain a fascinating material with particular sensorial qualities like semi-transparency and texture.

The Chicken Project (Figure 4.13 c) from Kieren Jones in the United

Figure 4.13
From bottom right, clockwise (a) Hidden Beauty by Studio Gutedort. (b) Coleoptera by Aagje Hoekstra. (c) The Chicken Project by Kieren Jones.

Kingdom presents a critical and speculative example of how to tackle a wicked problem such as mass overproduction and overconsumption of chicken. With a different approach to criticizing consumption, the designer experiments with chicken skin and bones (which become abundant and unused in the whole production and consumption phase of the animal) to find surrogate materials for cow skin and china ceramics. Although the project is more than a statement than a proper material development process, the intention of the designer to make visible resources that appear hidden in our everyday life opens doors to the awareness of the providence of objects, industrial processes and resources for product developments.

Animal Production

Our specie has always been dependent on animals for subsistence. Humans were hunters and gatherers before becoming farmers. Different from other animals, when hunting, not only do they eat the pray but smartly use its skin to protect the body or even build shelter. Once humans learned how to domesticate some animals, it became clear how they were more valuable alive, as they could produce different elements for subsistence. Sheep and Alpaca, for instance, are fantastic species are able to provide hair for clothing on a regular basis. Recently, human societies are in a stage of overproduction and overconsumption that are jeopardizing such species as well. If people stop seeing animal hair as a scalable material source, there is no need to harm animals to obtain their hair (e.g. such as the situation with angora rabbits). It is possible to get valuable sources for small local production just by grooming long-hair cats or dogs every morning, or collect it from a pet saloon every week.

It is crucial for humans to see the different possibilities elements that grow can offer. It is possible to contribute also to mitigate endangerment of species by acknowledging our impact on the planet as a dominant specie. Take human hair as an example, which grows 0,35 mm a day. If human race is reaching two billion people on the earth, it becomes a source worth studying. Even considering the fact that different from animals, people care about how to see each other and trim hair in fashionable ways to look different or to look better. Technology has reached a stage where is possible to assure that such fibers are free from any harm. People have so many types of hair that is possible to find different shapes and colour palettes to work with.

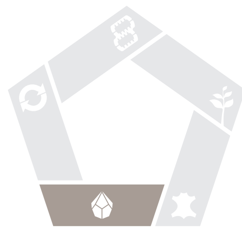
Two great examples arrive from Sanne Visser from the Netherlands and Studio Swine from the United Kingdom. The first one developed a project called the new age of trichology (Figure 4.14 a). In this project, the designer calculates around six million kilograms of human hair trimmed every year on a country such as Great Britain. All of this resource end up in landfills without any particular use. Her project suggests better use of the fiber. By experimenting with professional spinners, rope makers and knot specialists, Visser, creates two-ply ropes of human hair. The strings support loads of approximately 32 kilograms of weight and can come on different natural or dyed colors depending on the mixed fibers of trimmed hair. The second example is called hair highway (Figure 4.14 b) and explores the international hair trade based in the Chinese province of Shandong. In this region, a whole trade market of hair takes place and employs hundreds of people who collect, trade; clean, dye, and transform the fibers into a beautiful broom-like soft material. By adding a natural resin, the designers created a laminated material similar to the old animal horn

Figure 4.14
From top right, clockwise (a) The New Age of Trichology by Sanne Visser. (b) Hair Highway by Studio Swine. (c) Newool by Giada Lagorio. (d) Cooked Wool by Freyja Sewell.

and tortoiseshell, but without the harm and endangering species, that such materials represent. This is crucial, as it tricks the common eye that seeks the beauty of the animal shells based on the aesthetically appealing, and it can satisfy users' will by transforming human hair with a particular language without harming innocent animals.

Similar to human hair, wool is a fiber that grows regularly in animals such as sheep, goats, muskoxen, camelids and other long hair animals. Over the centuries, this material has been widely used to make different textile products and it is one of the most significant commodity fibers traded around the globe. Similar to the previous section, two examples dealing with this fiber with a DIY approach arrive from Giada Lagorio from Italy and Freija Sewell from the United Kingdom. The first one developed a project called Newool (Figure 4.14 c) which is composite made of glycerol, vinegar, water and potato starch. By cooking all ingredients in different combinations using the kitchen as a laboratory, the designer was able to create a stable material with similar properties like the ones obtained by industrial production of felt. Interesting to see here is also the colour combinations and palettes obtained by adding to the mixture, different spices. Similar to Lagorio, Freyja Sewell used the same ingredients, but instead of concentrating on the visual qualities of the material, she focused on the performative value of wool. The composite behaves well as an acoustic insulator. Therefore, the designer experimented with different ways to build acoustic panels. Her project named Cooked Wool (Figure 4.14 d), reveals how by heating the composite it is possible to construct various shapes to achieve a natural sound insulator.

4.4.3. Kingdom Lapideum



This kingdom contains all DIY-Materials which come from minerals: stones, sand, ceramics, clay, etc. Some current cases combine sources from other kingdoms, such as wool or cotton fabrics, but in a lower percentage compared with the primary constituent. Another feature of this kingdom is its strong link to crafts, probably because these types of materials have a long tradition in our material culture.

Every time a group of archaeologists somewhere in the world find evidence of previous civilizations, they find a collection of objects made of stones, ceramics or different types of clay. Working with our hands to carve earth stones and clays is part of human legacy. The design of this work connects firmly with these roots. From the arts and crafts that produce vases and pots with poetry and hand expressions to the clay models of the super advanced car design styling, many designers consider the mineral sources close to their field as the opposites of metals and plastics, probably by the autonomy that these materials allow without any aid of engineering and sophisticated machinery. When it comes to design not the project but the material itself for the project, many designers turn to ceramics, clays and stones to propose new alternatives. These alternatives can be recognizable as a whole family, as they all have in common some aesthetical and sensorial perception that links the materials with the human's desire to build with the hands.

When it comes to designing a material, it is essential to highlight that in many cases, the design of special DIY machinery or technique is considered part of this development. Tinkering with the material sometimes pushes the designer to invent or hack the machine to achieve the goal or sometimes the unexpected behavior of particular machine development, end up proposing a unique material mix with important expressive-sensorial qualities that would otherwise be impossible to achieve with traditional manufacturing standards.

This section aims to highlight auto produced materials that express through the link between ceramics and humans. Different examples will illustrate how sometimes the designer`s hands are enough to create a particular material, while in other cases, the designer's brain and the will of achievement of a specific idea, pushes some technological development to construct a material. In this family, the materials are also considered by their skin or surface. The surface of the material is the interface where the material enters in the relationship with the user. In a product, the user will first perceive the different qualities imprinted on the surface of the material from which the object is created (Rognoli and Levi, 2011 pp. 189). In this kingdom, designers pay particular attention to how to treat the surface of the material giving additional value to it.

Kingdom Lapideum is divided into: low crafted ceramics, high crafted ceramics, repurposed traditions, and other minerals.

Low Crafted Ceramics

Crafts by definition are opposite to industrial. While industry takes all the different technical knowledge of artisans and improves unit production and standardization, the artisan still feels unaffected. The artisan is more interested in the details. He or she concentrates on the transformation of unique pieces and enhancing the imperfection of a part like a knot in the wood or a stripe in the stone (Manzini, 1986, p. 28). Ceramics of ancient origin made of animal fat and bone mixed with ash and a fine clay date back as far as 24,000 BC, and different from any other material, the manufacturing processes remain similar. By applying heat upon processed clays or by drying a particular mixture of minerals at room temperature, these noble materials are a continuous source for designers to create.

Annika Frye from Germany (Figures 4.15 a - b) developed a DIY rotational molding process, in which polymer plaster is poured. The mixture doesn't need to be heated and hardens within 30 minutes. The Interesting thing about this project are the studies around improvisation. This is different from what occurs in industrial rotational

Figure 4.15
From top right, clockwise (a-b) Improvisation Machine by Annika Frye. (c-d) Balloon Bowls by Maarten De Ceulaer.

molding processes, where complicated molding settings are developed to assure longer batches of production. Here, the designer developed different molds out of PMMA sheets developed with simple geometric parameters obtained in CAD software to get every time a different unique shape.

Balloon Bowls (Figures 4.15 c - d) developed by Maarten De Ceulaer, the project defeats traditional industrial molding processes. By inserting a type of clay with a polymeric hardener in the middle of two air-inflated balloons, the designer can create unique shapes that would be difficult to obtain with industrial tools. Every piece becomes unique as the behavior of the balloon moulds is difficult to standardize.
The results regarding shape and visual texture are distinct from each other.

High Crafted Ceramics

As seen in **chapter two**, new craftsmanship and the modern artisans

Figure 4.16
Top left and bottom right (a-c) Marwoolus by Marco Guazzini. Top right and bottom left (b-d) Stone Spray by Kulik, Shergill and Novikov.

empowered with an industrial backend, thanks to the democratization of technology can achieve exciting results. While the means of production are trying to move towards automation and data exchange in manufacturing with what is known as industry 4.0, the traditional machines for industrial production which became the mainstream of engineering development in the past century are more reachable than ever before. A new army of technology crafted artisans is starting to produce materials by gaining access to industrial infrastructure or by hacking machines and controlling their behavior with the aid of simple knowledge of coding. This concept will come back in Kingdom Mutantis, but regarding this kingdom, it is important to highlight how some designers are achieving high crafting ceramics with the aid and support of this industrial back end. Different from what appeared in the previous section where some designers get inspired by traditional means of low-scale production of ceramics, others reach industrial-like materials by using sophisticated tools.
Marwoolus (Figures 4.16 a - c) is an excellent example of such achievements. Marco Guazzini, an Italian designer from the Tuscany

region, is connected with two old traditional districts like Pietrasanta, renowned worldwide for marble extraction and Prato, one of the major players in the textile industry. He combines marble dust with pieces of wool and resin to obtain a particular material. The colorful marble, resulting from the mix, can be cut, carved, sculpted and polished like traditional marble.

Stone Spray (Figures 4.16 b - d), is a project by Anna Kulik, Inder Shergill and Petr Novikov in which a robotic 3D printer produces shapes out of the soil. Additive manufacturing principle is hacked to develop a multi axed arm digitally controlled by a computer.
The machine collects sand and then sprays it from a nozzle combined with a binder. When the mixture solidifies, it becomes stable creating unique shapes and textures challenging to obtain with traditional methods.

Repurposed Traditions

The technological advancements of our society improve the way something is made either by changing the production technique or by introducing a different approach to achieve a similar result. This happens to many different objects and products which are made in a particular fashion like shoes, bags, glass vases or lamps. For many years those elements were constructed by skilled artisans, but due to the inevitable need to increase production, either the tradition was abandoned or replaced by a new efficient technique. In the DIY-materials kingdoms it is possible to see examples where the designer repurposes old traditional methods to create a particular element. It is an important strategy as it provides the designer with rich tools and techniques to achieve unexpected results.
Studio Glithero, applies one of the early principles of photography- the use of photosensitive chemicals - in a series of earthenware objects (Figures 4.17 a - b). This tradition, widespread in the nineteenth century to reveal images of different elements in paper and textile surfaces, is repurposed to give ceramics an exciting look. With an elegant bold Prussian blue, the designers achieved unique prints and decorations over the ceramic by meticulously arranging natural elements to cover parts of the piece before being exposed to the ultraviolet light. The contrasting result demonstrates how cross-pollination of techniques and materials can always be an excellent way to spark innovative uses of techniques industry does not consider viable, but that is

Figure 4.17
From top right, clockwise (a-b) Blueware Vases by Studio Glithero. (c-d) Kivi by Erin Turkoglu.

part of our material culture. This will also provide skilled artisans and craftsmen the possibility to apply their talent.

Erin Turkoglu, a designer from Turkey, developed Kivi (Figures 4.17 c - d), a material resulting from hammering clay into a mold. Resembling the way kids mix dough while playing, the designer blends different types of coloured clay. First, she pours the ceramic mixture into a workshop board, then when the clay becomes plastic and malleable, it is trimmed and placed inside the mold. With a simple compression molding technique based on hammering, the material is pressed into the mold to obtain the desired shape.

The Other Minerals

In the different sections of this kingdom, different techniques and strategies to produce ceramics, earth-ware and plaster by contrasting techniques and methods are apparent. This is proof of how vital these materials have been for our material culture over the years and they continue to be, given how they firmly connect to the hands like no

other material family does. However, there are also within this kingdom, some exciting developments of materials that are not related to traditional minerals. Curiosity and fearless experimentations, key components of the designer's mindset, reveal other sources for material development that sometimes are invisible to the average people. Dust, for instance, is perceived as an element of everyday nature. Most of the time, it covers up everything and is a possible source of allergies. Although dust is a collection of organic and inorganic elements and the less is known about its content, the better, some designers are seeing its potential as a material. Lucie Libotte from Belgium has collected dust in different cities (Figure 4.18 a). Once the grey powder full of tiny particles of any kind is fired and glazed like regular ceramic, it reveals a particular colour pattern. The designer states that an average of eighteen kilograms per year could be collected in every house just by sweeping away or vacuum cleaning it. This invisible material is an interesting resource considering that it doesn't need to be extracted from the earth like traditional clay.
Matilda Beckman based in Sweden also collects dust by vacuum clean-

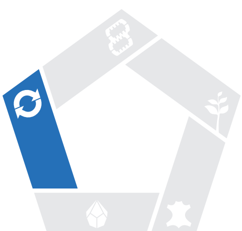
Figure 4.18
From top right, clockwise (a) Dust matters by Lucie Libotte. (b) Dust Furniture by Matilda Beckman. (c) Salt Pendant Light by Roberto Tweraser. (d) Stratum by Jongjin Park.

ing (Figure 4.18 b). She mixes the obtained resource with glue and water to get a high-gloss varnish resembling black marble. The final material is a composite with a particular aesthetic appeal. Although this case is closer to a kingdom recuperavit case, is worth mentioning in this section as it is connected with dust particles and, as we can see from the previous example, dust analysis on a microscopic scale reveals minerals such as lead, magnesium, salt, tin or zinc.

Salt or sodium chloride is a mineral not only abundant in nature but a central player in our road to civilization. Ancient people used salt to preserve food and it has been a fundamental part of human diet since the beginning of the agricultural revolution (Weller and Dumitroaia, 2005). Even wars and independence movements like the one conducted by Gandhi in 1930 known as the “Dandi March”, have seen salt as the protagonist. In this research, is possible to see also how designers take advantage of the different properties and characteristics of salt to develop material proposals. In particular, is the work of Roberto Tweraser, a designer from Malta who explored the possibility of salt to bind to create non-uniform and textured surfaces with some degrees of translucency (Figure 4.18 c). In his lighting work, it is possible to see a unique sense of aesthetics where the exposure of the salt-based material to light produce extraordinary results.

The final example in this section comes from a South Korean designer called Jongjin Park. In his work Stratum Ceramic Series (Figure 4.18 d), Park impregnates paper towels with coloured clay slip. Once wet, the sheets are arranged in layers and burned at 1280 degrees Celsius. The result is a unique material with machinability properties and stunning aesthetical language.

4.4.4. Kingdom Recuperavit



Comprise all sources that society considers a waste but can be transformed into valuable resources. They often come from plastic, metal or organic waste, sometimes as side products of industrial production. At the moment, this is the most significant kingdom considering the number of cases observed. Inside this kingdom, the designer`s intention towards a more conscious and sustainable future is clearly visible.

When thinking about modern humans, the image that comes to mind is the twentieth (20th) century expansion and population overgrowth that the era of discoveries and advancements of technology provides. The traces that this modernity is leaving to the planet, are recognizable thanks to a new group of substances and elements that are part of modern ways of living. These elements differ from the ones explained previously by two significant groups. The first one is the group of elements artificially made by humans. In other words, they cannot be found on the soil of the earth in that particular presentation. The other ones are the group of elements found in nature, but obtained in large scales of extraction and overproduction. The amount of these elements collected in a single place may even become a problem as the earth cannot digest them at speed equal to the ones gathered in the area.

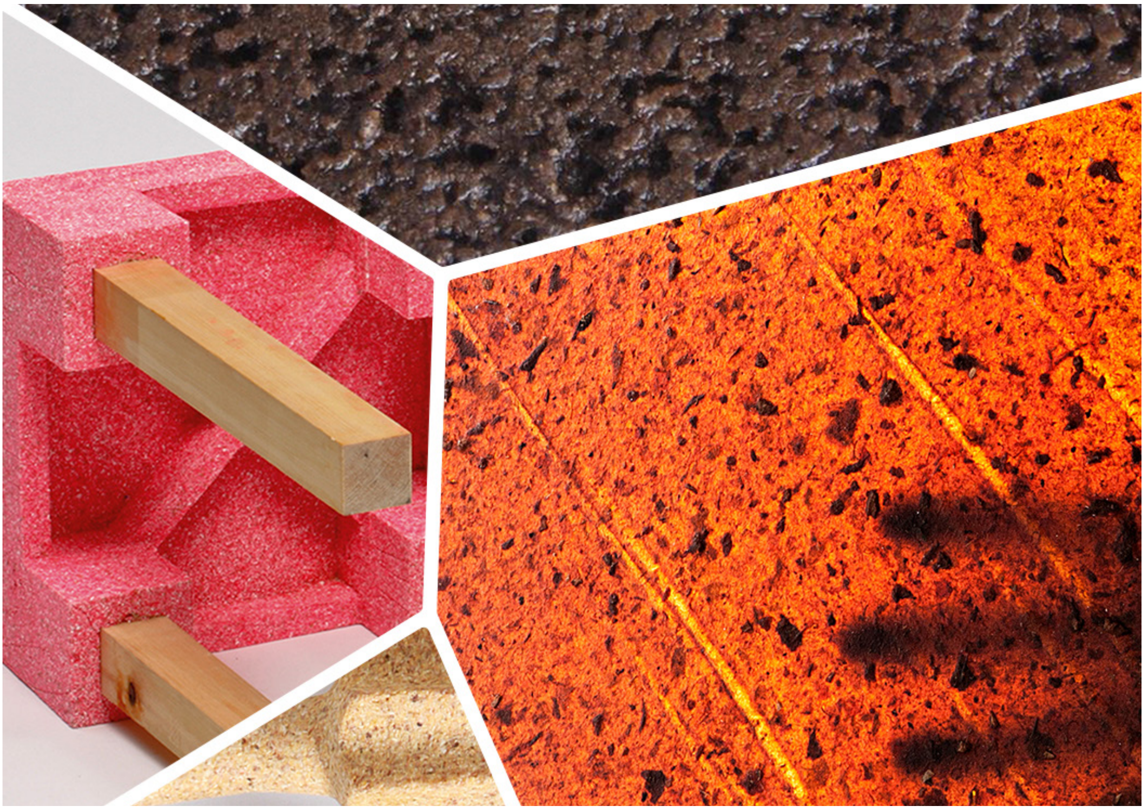
In the words of Michael Braungart and William McDonough, those two groups can be recognized as part of the technical metabolism for the first group, and part of the biological metabolism for the second (2010, p.103). Both are considered a health issue either for the planet, as well as for the living organisms inside.
Designers and other activists are starting to see elements of both groups as resources for new type of materials. These elements, are raw materials already extracted from the soil in one way or another, containing a significant amount of embodied energy and at the moment, free or compared with other industrial commodities and raw materials, very cheap. These new "raw" materials with some creativity will become essential players in the definition of new means of production and consumption in the near future. This way of thinking is not new and is part of the DIY culture which has always been trying to find creative solutions at home or in a small-scale business with discarded pieces or materials. Nowadays, it is become a common trend among creative disciplines and especially in design as the methods and the tools to transform these new raw materials into something useful and meaningful are available to all.

The aim of this new trend of materials development and conceptualization of new possible products is to recuperate. It is adding a new "r" to the well-known philosophy of reducing, reuse and recycle. Recuperate means to see what humans call garbage or waste as a fantastic resource. This kingdom is massive and is gaining more and more attention. As the new generations are more aware of the limits of growth and the dangers of exhausting extraction of resources, this counter-trend could open a detour for new languages, as alternatives to industrial ones made by machines in big scales.

Kingdom Recuperavit is divided into: recuperating food sources, recuperating natural sources, recuperating industrial sources, and recuperating common waste.

Recuperating Food Sources

Dealing with food “waste” is an ethical issue. Critical questions like the overproduction of food; the unbalance of the food supply in the world and the unhealthy industrial production of aliments emerge. Also, the way food is packaged and transported is becoming critical. In the words of Michael Ashby “Waste is only waste if nothing can be done to make it useful”(2013). There is so much to learn from nature, in particular, by understanding how in nature, the concept of waste doesn't exist. Spend a couple of minutes outside your house where the organic “waste” is deposited. From birds to ants, you will see an army of animals arriving to take advantage of the things humans do not consume, probably because they are not edible or tasteful like skins or peels, or because the primary nutrients, aromas and flavours like coffee or tea are already extracted. In a country like Colombia (and in many others) is also common to see not only animals who come and gather what people discard, but also homeless who find in “trash” a full meal. It is not the intention of this section open a discussion on how to feed animals and humans. Instead, the previous example only shows how resourceful organic waste can be. It is something designers should not tackle alone. There are hundreds of risks and health concerns when dealing with these type of sources, and yet, hundreds of opportunities as well. Awareness of the fact that many of the things automatically thrown away are valuable is the first step. The organic sources can be further studied to create surrogates and replacements for many inorganic counterparts which are discarded and are difficult to break apart by nature. The Second life of organic sources (as waste is a word not worth using anymore) is a must. There are so many objects in our daily life to rethink and so many ways to transform organic matter into useful applications for short periods of time that designers need to consider materials coming from recuperated food elements as a resource for their creations. Second life is a tough concept for people to understand, as humans by nature are unable to have one. Despite that, it is possible to do something meaningful with



organic leftovers before giving them back to earth to feed the biological metabolism.

Figure 4.19
Left (a) Eggo by Sebastian Aumer. Top (b) Decafé by Raúl Laurí. Bottom (c) Apeel by Alkesh Parmar. Right (d) Fruit Leather Rotterdam.

This section further explains this issue by looking at the exciting material development some designers have embarked on. The first case to describe is from the German designer Sebastian Aumer (Figure 4.19 a). In a country with a long tradition of baking and bread making, Aumer has found how every day tons of eggshells come out of every single bakery producing a considerable number of organic leftovers. He decided to collect them and experiment using ingredients such as casein, vinegar and starch. After two hours of baking, the final result is a composite of 70% coloured eggshell with a vibrant texture and appreciable mechanical strength.

Decafé (Figure 4.19 b) is an ongoing project by Raúl Laurí from Spain in which the primary concern also derives from the excessive amount of food waste produced by humans. Every day Coffee leads to millions of tons of garbage. It is estimated that in a country like Italy, people consumed approximately five kilos of coffee per capita in 2017 (Statista 2018). The designer intends to convert this immense resource into a material with a particular sense of aesthetics that can be used to create different products. The coffee grounds are collected and mixed with a natural binder, pressed and heated obtaining a solid material that resembled the texture of concrete but with the earthy colour palette of coffee beans.

Fruits and vegetables are a fundamental element of our balanced diet. As mentioned in kingdom vegetabile, many of those fruits and vegetables come naturally packaged and covered with skins and peels. Being farmed in significant quantities, these skins or even the fruits that are not consumed on time can be used to develop different kind of biopolymers and are subject of constant study by different disciplines. In this section, two cases in which the use of this resources can show possibilities for new product development are shown. The first one is a project called Apeel (Figure 4.19 c), by British designer Alkesh Parmar. In this project, the designer transforms citrus peel into a new material with a wide range of potential uses, without needing to use additional binders. He dries, blends and mixes them with a secret combination of all natural, organic elements to create a firm and robust, flexible sheet with a subtle matte texture. The second case comes from a collective of designers from the Netherlands called Fruit Leather Rotterdam (Figure 4.19 d). By collecting the different rotten or other unsellable fruits and vegetables of the local market, the collective applied an old recipe that chefs use to decorate dishes called fruit leather but on a larger scale. The result is a semi-translucent material with a certain degree of flexibility. It can be coloured in different ways depending mainly on the type of fruits used for the material development.

Recuperating Natural Sources

Natural sources are not necessarily a problem. Different from food overproduction it is possible to find different opportunities for material development by recuperating leftovers from a wide range of sources. Once again the trained eye of the designer is what plays a crucial role in identifying resources which can transform into something meaningful before returning to the soil and could replace inorganic materials in a wide range of critical applications. In the book Cradle to Cradle, the authors criticize the common desire of perfection and geometrical management of our natural resources like grass or bushes in the garden (p.32). The authors criticize the anti-natural behavior of the modern society where everything should look perfectly trimmed and they also point out how much time and energy people spend removing every centimetre of grass and bushes, fighting against the natural growth of plants. It is unlikely to change as modern architecture trends tend to influence this kind of behaviour more and more. Still, it is possible to see it as a continuous resource for material development. Every time our city is "made beautiful," all sorts of resources are cut off and could be used again. There are few studies around the embodied energy these resources can carry (different from industrial materials) (Ashby, 2013 p.119), but it is important to find relevant numbers by measuring the whole cycle from trimming to the landfill of this resources to recuperate this energy creatively. If the amount of annual co2 released to the atmosphere by wood and paper industries is considered (average 109 tons/year), it is possible to see how they slightly exceed commodity plastics (average 108 tons/year) (op. cit.). These industries, do not consider the upper part of the tree or the crown as useful. This consideration is grounded on the difficulties to find homogeneity and because the leaves do not provide any use

Figure 4.20
Form top right (a-c) Bloodbricks by Jack Munroe. (b-d) Merdacotta by Locatelli and Cipelletti.

(Kula, 2008 p. 15). Instead, designers can discover in those unwanted resources essential elements for different scale projects, which in return can balance carbon footprint positively.

Equally important to what happens with this sort of vegetal resources (they could be part of Kingdom Vegetabile as well as explained later), there are also some other resources to consider coming from organic resources. More complex from the ethical point of view as they deal with animals, they are equally important as their use can impact society significantly, by replacing other materials in short-term applications.

Coming back to the overproduction of food, particularly with the over-consumption of meat from different animals, some elements are barely considered and they could represent an alternative. Blood, for instance, is a vital liquid that ensures life. However, when millions of animals are slaughtered to supply our food chain, this precious liquid is discarded in large quantities. It can be studied as a possible resource to tackle other problems and Jack Munroe from England has found a reasonable way. With his project Bloodbricks, after an in-depth study of traditional animal slaughtering techniques such as halal and shechita (Velarde & Dalmau, 2018), Munroe experiments to create brick out of blood and sand (Figures 4.20 a - b). Understanding the coagulation process of blood and by gaining knowledge of the right temperature to dry and cook the block, it is possible to obtain a reliable and stable material. The whole process is also considered circular if the experimentation is applied in arid desert zones where the animal blood, the sand and solar ovens are widely available.

Similarly to the previous example, Gianantonio Locatelli and Luca Cipelletti From Italy, have encountered a novel way to use another commonly unwanted resource: cow dung (Figures 4.20 c - d). Merdacotta is a project exploring the possibilities of an abundant material such as animal feces. The feces are widely transformed into manure by mixing bedding straw with it and are widely used as an organic fertilizer. Despite that, considering the number of wastes that a local farm can daily produce, another source for material development arises. The animal dung goes through a biogas generator, which extracts methane to produce energy leaving a dry and odourless base source. Afterwards, it is mixed with straw and clay and cooked in an oven, creating a material similar to terracotta ceramics.

Recuperating Industrial Sources

As previously discussed, Industry produces an enormous quantity of leftovers, which are not suitable to feed animals and organisms. In fact, they should be kept away from any natural ecosystem to avoid damage to it. Many industries reuse their leftovers and have an industrial closed metabolism system (McDonough & Braungart, 2002 p.109), but many others don't. In different countries where regulations and legislation are not as strict as in Europe or North America, even big companies avoid investing in waste management as it is not mandatory. Designers need to be more aware in countries and cities of origin, not solely with the role of environmental agents looking for bad industrial practices, but as material hunters. It is crucial to gain experience in identifying possible resources for the materials development of projects.

The common saying "energy can neither be created nor destroyed; rather, it can only be transformed from one form to another" attributed to Albert Einstein and the pillar for the conservation of energy law is an excellent point of focus when it comes to recuperating industrial waste. People tend to believe that recuperating production by-products, industrial rejects and consumables of our economic, industrial society is only a matter of sustainability and environmental concern. it Is not far from the truth, however, when seen with sharp eyes, that there is a hidden treasure regarding embodied energy waiting to be used. On average, metal, plastic, ceramic and hybrids industries produce and embed in their materials between 50 and 102 megajoules per Kilogram[9]. Many of these materials, when entering into the second step of transformation namely, manufacturing, remain as industrial leftovers as scraps, offcuts, residues and dust or as unsellable goods because of a batch defect. Designers can see them as an inexhaustible source for materials and projects. As a matter of fact, companies and industrial consortiums are starting to become aware of the potential and it is common nowadays to see initiatives, contests and research projects inviting designers into think tanks to propose alternatives and smart use of these residues. Designers can do more than just imagine applications for these industrial left overs. Using and transforming them as raw materials themselves is something to consider.

9. Data obtained with (Ashby 2013 pp. 477) and accompanying CES EduPack software.

Studio Ilio, a UK based studio founded by Fabio Hendry and Seongil Choi experimented with different discarded waste that could melt around an electrically charged wire. After testing with different polymers, they found that the polyamide used in the Selective Laser Sintering (SLS) process, together with cristobalite sand could produce a solid material once it is cured (Figure 4.21 a). As the three-dimensional prototyping and manufacturing technologies are increasing, the discarded powder of the SLS process has become readily available. Around 44 percent of the powder used during the sintering process is dumped. With a DIY electric wire box heating the dust up to 500 degrees Celsius, the designers can create a material which could take almost any shape.

Inspired by the principle of candy-floss machines, Emile De Visscher, Audrey Gaulard, Nicholas Paget and Christophe Machet from France developed a project called The Polyfloss Factory (Figure 4.21 b). In this project, a custom-made machine transforms discarded thermoplastic into a wool-like fiber that could be used for several applications. The designers state within the project how, with such an approach it is possible to operate in small-scale circles of reemployment, which is rare for polymers, as they are usually and historically dependent on significant scale manufacturing and production batches to be profitable.

Figure 4.21
From left, clockwise (a) Hot Wire Extension by Studio Ilio. (b) Polyfloss Factory by De Visscher, Gaulard, Paget and Machet. (c) Structural Skin by Jorge Penadés. (d) Stone Cycling by Tom van Soest.

Jorge Penadés from Spain, analysed the production cycle of leather, which remains invariable since ancient times. The leather is highly appreciated worldwide by its properties and aesthetic qualities, yet is very inefficient as material as a lot depends on the size of the animal (Figure 4.21 c). Regardless of the application as the original format of the skin is irregular, every single piece of leather produces waste. The designer experimented with scraps from leather production and came up with a robust material by fixing the leather source with bone glue, an adhesive created by prolonged boiling of animal connective tissue. The result is called Structural Skin, a solid structural material with tensile and compressive strength, fire retardant and good isolation properties.

The last example in this section comes from the Netherlands. Stone Cycling is a project developed by Tom van Soest who started grinding and blending glass and ceramic waste with leftovers of clay from the brick industry (Figure 4.21 d). After several experiments and recipe tunings, the designer obtained a series of bricks with different colours and textures used as construction material. This upcycling process is accompanied with a whole range of names and descriptions evoking pastry and food bars. As explained in the conditions for a DIY-Material development, storytelling is a crucial element of the entire process of material development. This class of materials with creative naming, CMF development and narrative description like stone cycling are great examples of this.

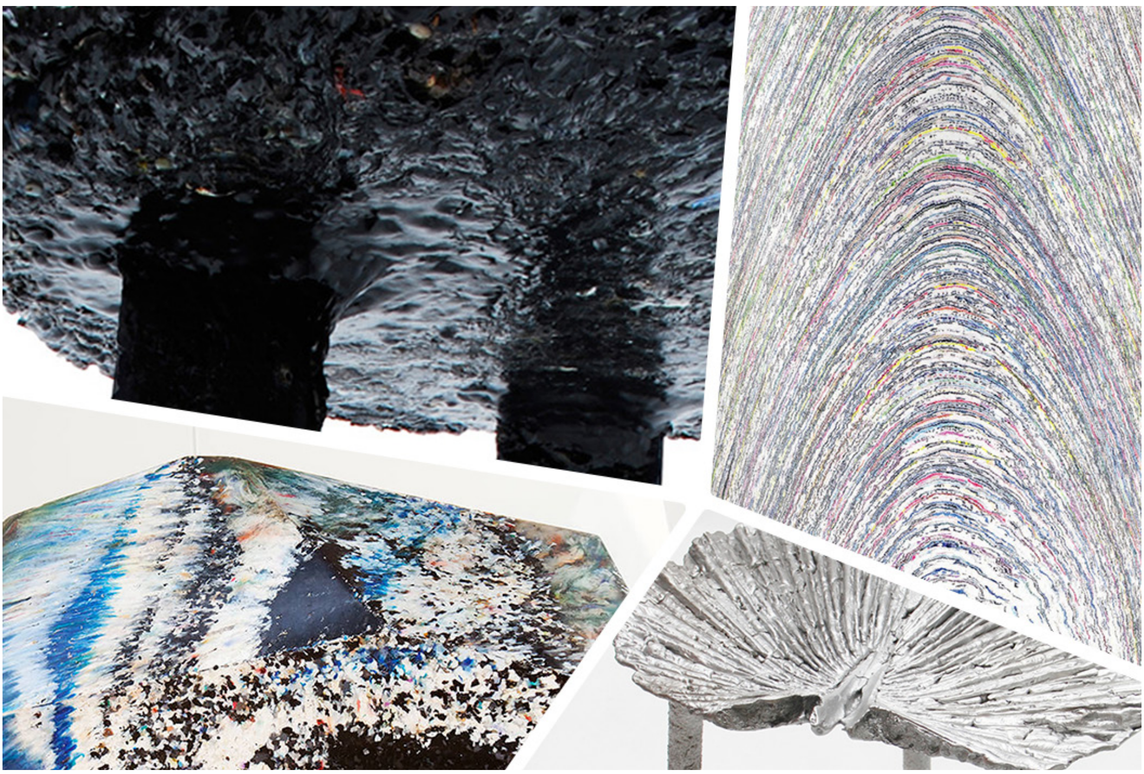
Recuperating Common Waste

Throughout this kingdom different sources classified depending on a natural or industrial origin have been discussed. However, there are some elements of mixed provenance, which can belong to another sub-category.

Common waste is a term used to describe all unsorted discarded waste on a daily basis. It comes in such amount into different places that it may become almost invisible (Freinkel, 2011 p.141). Buying plastic-packaged food is so common that people don't calculate how long the packaging lasts. Plastic is not bad and is not worth declaring an open war against as is happening in recent years. Is not plastic's fault, it is humans' fault. As designers, consumers or industrials people rely so much on plastics as a commodity that the implications of its use on a large scale are not being considered. Let's take the PET bottle as an example. It was conceived in the early seventies by the North American engineer Nathaniel Wyeth to contain and transport gas-based beverages and it was a breakthrough concerning weight and performance that the use spread quickly around the world (Bürki-Spycher, 2012). Today more than forty years later, water, juices and all gasless beverages are packed, transported and even dispensed everywhere. The material is not only used incorrectly but is used incorrectly by too many. Examples like this are easy to find anywhere and are jeopardizing our future as a society. Some designers have started to think of ways to deal with this wicked problem by giving new meaning to these resources. Dave Hakkens, from the Netherlands, created an open source project called precious plastic. By designing a DIY machine and publishing online resources, the designer started to promote a worldwide community devoted to recuperating plastic waste and transforming it into something different (Figure 4.22 a). Let's hope the community creates something meaningful.

Figure 4.22
Bottom left (a) Precious Plastic by Dave Hakkens. Top left (b) Sea Chair Project by Studio Swine. Bottom right (c) Can City by Studio Swine. Top right (d) Newspaperwood by Mieke Meijer.

Another exciting initiative comes from Japanese Architect Azusa Murakami and British Artist Alexander Groves of Studio Swine in



association with Kieren Jones (Figure 4.22 b). The Sea Chair Project is an inspiring case where the designers embark on a quest to collect plastic from the sea. As is known the different plastic garbage patches in our oceans contain millions of plastic scraps degraded by sun exposure and becoming so tiny that marine life consumes them, and consequently plastic waste has entered in the food chain (Duis and Coors, 2016). By collecting part of this scraps, the designers create simple objects with rough aesthetics, but with a potent message. They attach to the object a tag with the coordinates where the plastic source was obtained. It is an excellent example of providing awareness not by pointing at and judging people's behavior but by inspiring people to reflect.
The same studio proposes another case worth mentioning in this section. It is called Can City and consists of a DIY mobile foundry built to cast recycled aluminium from the streets (Figure 4.22 c). The project takes place in Sao Paulo, Brazil and is inspired by the work of waste collectors known as Catadores. The project reveals how it is possible to mine the city to find countless sources of materials. In fact, in Latin America, this is a practice of subsistence for many individuals as there is a lack of structured recycling infrastructure. This example represents methods of the "Third World" which, for years, was seen as backward and undeveloped, but has now become a subject of study to help tackle environmental and social issues of industrialized societies.
Newspaperwood is a project developed by Mieke Meijer from The Netherlands. By stacking and binding sheets of newspaper, it is possible to obtain a layered material (Figure 4.22 d). When this material is cut into planks, it reveals grains or rings that resemble ordinary wood. "it Is like reversing the wood to paper process" states the designer. The new material has properties similar to standard wood and is also easy to machine and process with basic tools. One of the unusual characteristics of this material is that unlike natural, unprocessed wood, it can be meticulously designed adding layers of coloured newspaper to obtain unique patterns of the grain.

4.4.5. Kingdom Mutantis

This Kingdom includes the DIY-Materials created from different technological mixes and hybridization of industrial, interactive or smart sources (Ritter, 2007 p. 47). In this category, it is possible to see combinations of varying material sources that come from another kingdom but evolve into something particular with the aid of any technology. This transformation represents a significant change in the material's nature and behavior in comparison to other kingdoms.

According to the field of biology, mutations play a role in both normal and abnormal biological processes of life including evolution. Some mutations are hereditary which means they are passed down from a parent to the offspring while some others occur by the exposure to particular environmental conditions. It is common to see in the fields of biology and genetics how these variations appear by errors or changes of a specific code inside any natural building block. In design, this is likely to happen as mistakes and code changes are infinite sources of innovation. One of the more recognizable characteristics of designer's way of thinking is to consider errors as part of the process. Learning from them or enhancing something that went "wrong" sometimes could lead to unexpected results. These outcomes will hardly appear by following a linear chain of thoughts and experiments, typical from STEM-related fields. **Chapter two** explains how, according to Rongoli et al. (2015), imperfection, dynamism and self-production are three strategies to address a materials experience. In the DIY-Materials theory, and in this kingdom, in particular, this combination of strategies provides evidence of unique results.
Either by hereditary transmission of material characteristics or by the influence of environmental conditions, in this section, different mutations leading to exciting results of DIY-Materials are presented.

Kingdom Mutantis is divided into: industrial mutations, interactive mutations, and material mutations.

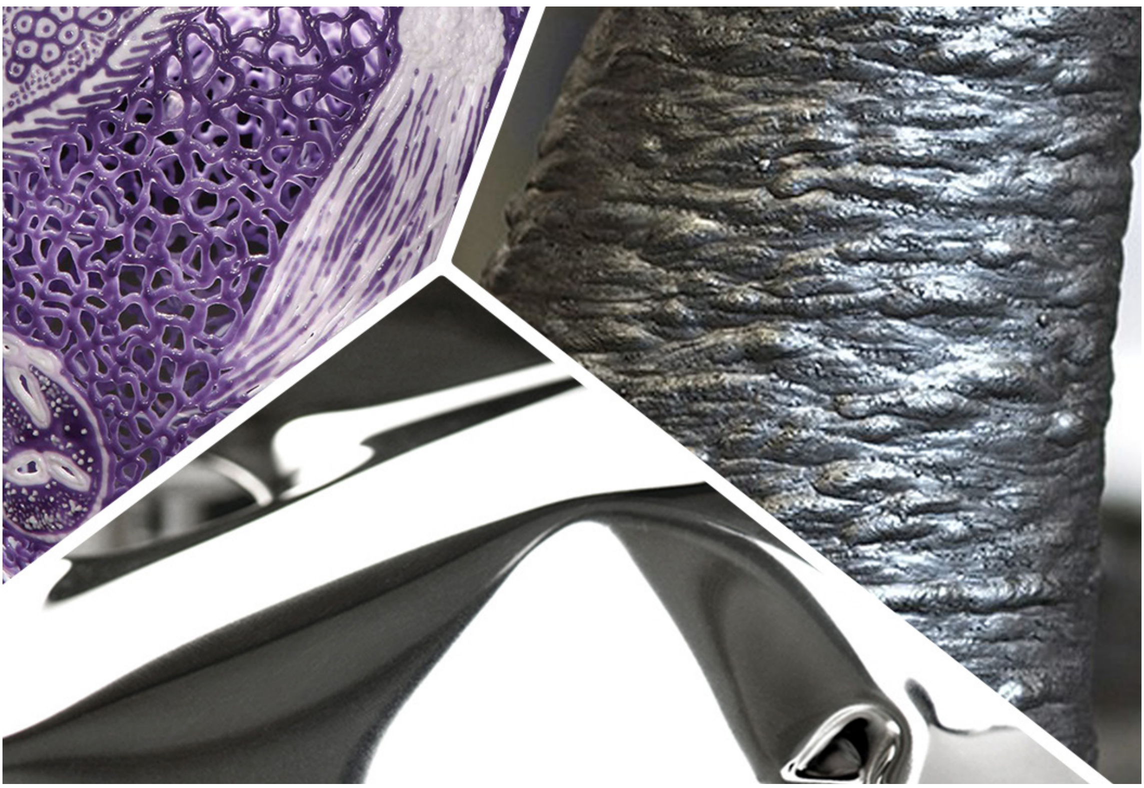
Industrial Mutations

Hacking, a word with its origins in the German word Hacken[10] is a fantastic definition to explain the way of intervening, unmounting or cutting into pieces a particular structure or system. Hacking is a word misinterpreted by many as it connects with illicit behaviours of some software programmers. In the materials domain, the hackers are the same artisans and bricoleurs, who learn by unmounting and transform by changing the core behavior of a machine or a particular tool, to achieve a result. In the words of Stefano Micelli (2011), the real value of artisans, compared with an industry workers lies in their capacity to domain the craft and is a result of constant improvements of the tools and machines (p. 22). Designers who have access to tools and

10. According to the Pons German Dictionary, the word hacken means to chop or separate.

machinery of different kinds, can create improvements and change behaviours of the devices by introducing new techniques. This process leads to achieving new materials and subsequently new products with particular languages. Gaetano Pesce was one of the first designers to take advantage of machine errors and some of his masterpieces are the result of hacking a particular machine to obtain uniqueness and novelty. Pesce highlights a productive scenario in which the factories are open to self-production and serve creativity (Martino, 2007 p. 31) Following his steps, some contemporary designers transform processes to obtain interesting DIY material mutations. Oskar Zieta from Poland creates objects with a balloon-like metal material obtained by welding and blowing metal sheets. The designer developed a new technology called FiDU, which stands for the German 'Freie Innen Druck Umformung,' or free inner-pressure deformation. To obtain a shape you first laser cut a pair of one-millimeter thick metal sheets then weld them on the edges. With the aid of water and air pressure at approximately 0,4 bar the desired shape start to form. What is interesting about this technique is to see how a solid and robust material like steel can suddenly be perceived as lightweight and crumple up like paper (Figure 4.23 a).

Figure 4.23
From bottom, counter clockwise (a) FiDU by Oskar Zieta. (b) Mx3D by Joris Laarman. (c) Green by Sebastian Straatsma.



Mx3D is another example of technological mutation. Developed by Joris Laarman from the Netherlands, this hybrid technology combines an industrial multiple axis robot with a welding machine. The resulting material is a printed 3D metal that can be shaped in different ways. Several types of metals can be processed with this technology allowing designers to create different solutions with a particular aesthetical language (Figure 4.23 b). The metal printers originated from the desire to obtain shapes bigger than the box of a standards 3-D printer and this technological push is allowing the designer and the new team of partners to develop architectural scale projects.

Sebastian Straatsma evokes the work of Gaetano Pesce of the serie diversificata (op. cit.) objects composed with material errors and mixes produced by altering a machine (Figure 4.23 c). The idea of Pesce to do research on the new typologies of construction and new production instruments where imperfections make an accountable value has been topic of inspiration for some designers specially when the "errors" provide uniqueness. These unique shapes, colours and finishes are very difficult to obtain with controlled standard manufacturing processes.

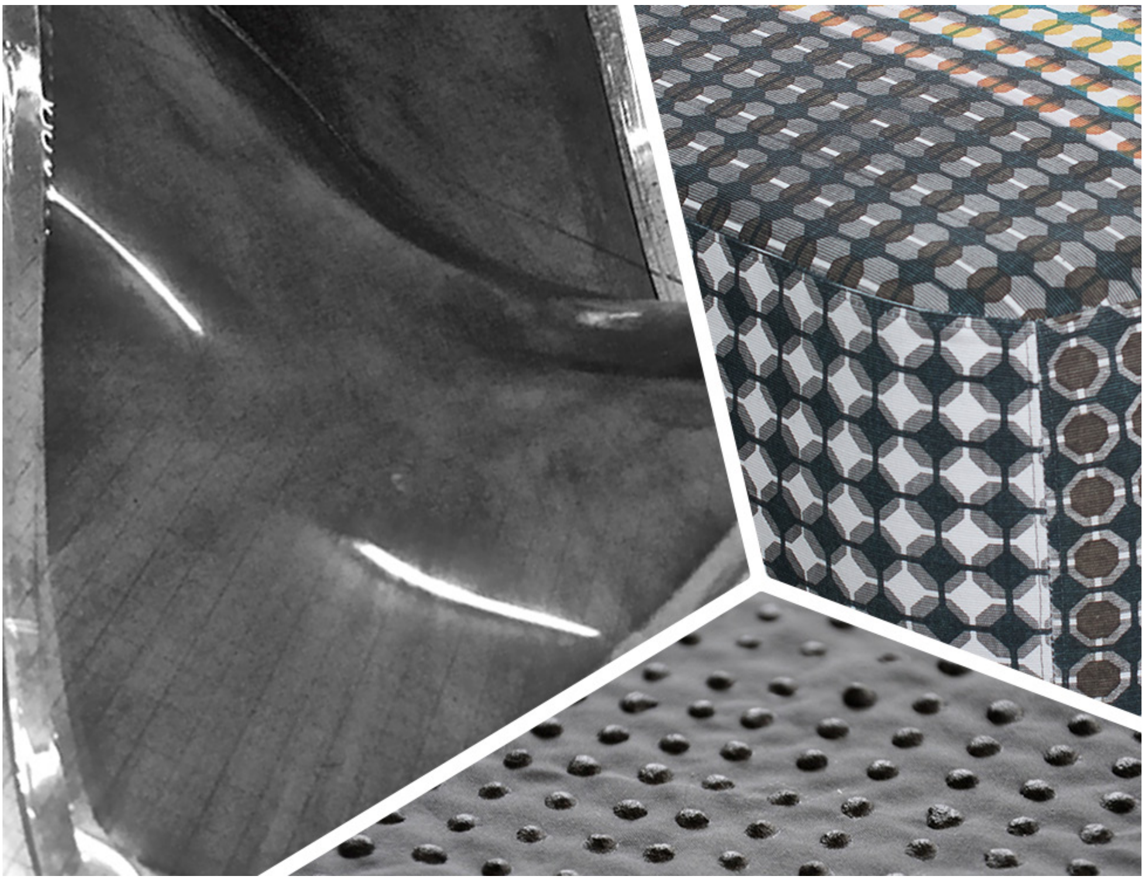
Interactive Mutations

Thanks to the integration of disciplines and theories between Computer Sciences and Design with the contributions of Bill Moggridge and Bill Verplank in the eighties, the idea of interaction became relevant in the field of design as it highlighted the importance to focus on behavior (Cooper et al. 2007 p.xxviii) (Moggridge, 2007). Ezio Manzini connected this idea of behavior with the materials also in the same decade (Manzini, 1989 p. 44), but equal to what happened with Moggridge and Verplank theories, almost a decade passed before their concepts were understood. The field of interaction design provided significant tools to intervene in the behavior of materials by programming and controlling properties and qualities. The advent of open source circuit boards which started with Wiring, Arduino or Raspberry some years ago, allowed designers to control materials behavior and activate interactions between people and the material. It is still a material design approach facing an embryonic stage. Some technological advancements may happen before this circuits and computational capabilities could be embedded into the material. However, different designers are manipulating properties with the aid of these tools and envisioning alternative futures.

Karmen Franinović from Croatia and her research team experiment on the threshold between the mechanics, chemical and electronics. The results are materials that illuminate, have sound and move when electric currents pass through. Membrane structures called Electroactive Polymers suggest a new kind of responsive behavior thanks to soft and organic movement (Figure 4.24 a). Franinović calls these materials enactive which explores notions of agency, materiality and interactivity altogether.

Magnetic fabrics is a project undertaken by the designer Lilian Dedio. Arranging magnetic components in various patterns inside a textile, the material gains life with the aid of media and electronics (Figure 4.24 b). When the magnet reacts to a stimulus, the textile begins to move creating a dynamic behavior. The visible part of the magnets over the textile also creates a unique aesthetical language that changes over and over when the entire material is in movement.

Figure 4.24
From left, counter clockwise (a) Enactive Materials by Karmen Franinović. (b) Magnetic Fabrics by Lilian Dedio. (c) IRE by Vallgårda, Nilsson, Satomi and Worbin.



Anna Vallgårda, Linnéa Nilsson, Mika Satomi and Linda Worbin from Denmark experiment with a type of materials they call computational composites. These materials are the result of blending any standard material with a computational layer which shows some desirable properties that can be controlled by the matching of both sources of the composite. In the project IRE möbel footstool, Vallgårda and her team developed a woven cotton textile embedded conductive thread on one side, and a colour print pigment with thermochromic ink on the other (Figure 4.24 c). The conductive threads are resistive enough to heat up when the current is let through enabling a colour change in the print through controlling the current.

Material Mutations

Material hybrids and composites are one of the four categories of the so-called engineering materials. Inside this category, it is possible to find a whole universe of materials composed of two principal elements with specific properties or characteristics to add to the composite: The matrix and the reinforcements. Sometimes they can include a third element called the core. The development of a composite aims to obtain an improved material with augmented properties compared with the original matrix material (Cornish, 1987 p. 135). Recently, designers have embarked on similar quests for hybridization and compositions of two or more elements. Probably the aim is not one of the engineers seeking for a particular performance, but it is also research on sensorial improvements. These mutations resulting from the mix of two or more base materials, different from composites, evolving into new material languages capable of envisioning future applications challenging to imagine before.

Martin Pohlman, Julian Schwarze and Johannes Wöhrlin from Germany have developed during their studies at the materials design institute in Offenbach a material called Paralightskin (Figures 4.25 a - b). This hybrid material combines the performative properties of silicone with the haptic and visually appealing characteristics of leather. Parametrically designed and cut, the leather adapts to the shape of the composite and the silicone pops up in different open spaces to provide visual feedback as a response to touch and pressure.

Elisa Strozyk from Germany experimented with a wood veneer of 0.6 mm, laser cutting it and manually arranged the pieces over a support cotton fabric. The result is a flexible wooden surface with appealing aesthetics and tactile experience. Wooden Textiles lie somewhere between hard and soft. They have the familiarity and appearance of natural materials but at the same time surprise, as the wood can move and form in unexpected ways (Figures 4.25 c - d).

In this section, it was possible to see the behaviour of materials which presents additional degrees of intelligence compared with the ones belonging to the other four kingdoms. These degrees of intelligence are possible thanks to the addition of computational capabilities, and hybridization of design with science (Antonelli, 2008). Technological advancements, miniaturization, and democratization of different technologies help designers to propose novel materials and envision future scenarios of use. Different from the conventional smart materials (Ritter, 2007) the materials of this kingdom show additional degrees of interactivity and evolve into something particular with the aid of any technology. Thanks to this behavior, Kingdom Mutantis materials were included in a parallel research entitled ICS Materials, which stands for Interactive, Connected, and Smart Materials. In this

Figure 4.25
From bottom right, clockwise (a-b) Paralightskin by Pohlman, Schwarze and Wöhrlin. (c-d) Wooden Textiles by Elisa Strozyk.

research, a team of colleagues led by Valentina Rognoli evaluates intersection of design, new materials, and interaction (Rognoli et al., 2017; Parisi et al. 2018; Ferrara et al. 2018).

4.5. Interrelationships between kingdoms

It should be emphasized that although in this chapter different materials were categorized into five kingdoms, many cases fall under two or more categories. In other words, the borders between these kingdoms are not strict but loose. This classification is of great help not only when it comes to identifying the different types of DIY-Materials produced, but also when it comes to creating them (**see chapter five**). Likewise, we can understand how a case can belong to two kingdoms, build a bridge between categories and enrich the definition of a material showing advantages, characteristics and properties from each side of the categorization (Figure 4.26). Projects like Fruit Leather or Marwoolus are a great example of this statement. The first one belongs to kingdom Recuperavit based on its foundations to recuperate food sources being thrown away daily in the different markets in our cities. However, given its condition as a natural vegetal source, could be considered as a farmed material from kingdom Vegetabile as well. The second one is part of the high crafted ceramics family inside kingdom Lapideum as the material emerges by setting industrial machinery to achieve a desired will of the designer. At the same time, it is a material produced by smartly recuperating, leftovers from two industries of the same region blending them in into a novel material, fitting into kingdom Recuperavit as well.

4.6. Discussion

This chapter aims to illustrate the different categorization and subcategorization of the DIY-Materials. It was part of the work developed during the first year of the doctoral research and continued to grow and refine during the rest of the Ph.D. The decision to include in this chapter the whole description of the kingdom containing significant cases from designers responds to a way to contribute to a better understanding of the whole phenomenon. This categorization became crucial for the development of the further studies presented in **chapters five, six, seven** and **eight**. Instead of making a list of cases with a short description, it is more useful to describe the kingdom and its sub-categories through explanatory text and to embed the differ-

Figure 4.26
Interrelationships between kingdoms. One case can belong to one or more kingdoms.

ent examples inside this text. Not all the cases studied are included in this chapter but appear listed in **chapter five** and the **appendix**. The boards of each subcategory were constructed with the different images collected and arranged in a way to highlight the material and not the application. The reason behind this decision is to connect the description of the kingdom and the subcategory with the image and not directly with the cases. All images were taken from the designer's websites, and their credits appear at the end of the dissertation. This dissertation does not intend to claim credit for the images, and the authorship remains with the designers and the photographers linked to the project. The composition of the image has a more illustrative goal like any material or mood board.

This categorization is a way to see the DIY-Materials in a particular order. It is not the only one, and the same materials can appear in other publication as Radical Materials (Franklin & Till, 2018), Sustainable Materials (Thompson, 2013), Neo-materiali (Pellizari & Genovesi, 2017), Grown Materials (Lefteri, 2014) or Alchemic Materials (Lee, 2015). For the DIY-Materials theory was crucial to arrange the different cases in this type of classification. Following chapters will show how this classification gained relevance for the different studies conducted through the doctoral pathway.

4.7. Conclusion

The fourth chapter aimed to provide the categorization and sub-categorization of the DIY-Materials phenomenon by analysing and organizing the different cases. Making this categorization was a vital step of the research as it helped to improve understanding of this phenomenon. Different to what was initially published by Rognoli et al. (2015), inspiration came from the work of the Swedish botanist, zoologist, and physician Carolus Linnaeus called Systema Naturae (Linnaeus, 1740) - known as Linnaean taxonomy. This taxonomy gave to the classification of the phenomena a remarkable and delightful source for naming the categories. Apart from the first three categories similar to the ones of Linnaeus, other two families of cases were forming also based on their primary sources more related to the human intervention.
According to the Working Hypothesis **(WH1)** posed at the beginning of the research: *The DIY-Materials phenomenon tends to grow. There should be a way to organize it to allow a better understanding.* The categorization of the DIY-Materials into kingdoms prove right this hypothesis, as it provided scientifically order and allowed a better framing to understand the phenomenon.

The initial categorization work was presented in 2017 in the Eksig 17: Alive. Active. Adaptive. International Conference on Experiential Knowledge and Emerging Materials, Rotterdam-The Netherlands with the title: Five Kingdoms of DIY-Materials for Design. (Ayala-Garcia, Rognoli, & Karana, 2017). Since then the classification has evolved by deepening the analysis and adding sub categories.

The written style to present the classification of these kingdoms in this chapter differs from the structure of how the studies were conducted in the next sections and with standard academic writing. Is written this way on purpose to allow this chapter to stand by itself and to be read independently. The different cases since the beginning of the research received an assignation of codes for the different measurement and analysis instruments, and those numbers correspond to the order of appearance in the collection phases. These codes are visible in **chapter five**, however, understanding the kingdoms with this system is far more complicated. The way to present them without connection with the codes, as it appears in this chapter, helps in the full understanding of the DIY-Materials phenomenon. The following section will focus on the evaluation instruments that allow gathering qualitative and quantitative information about the different kingdoms. The evaluation in the next **chapters five and six** will remain on the kingdoms level without the subcategories. This is mainly due to the different datasheets resulting from the analysis and the database created before.

Chapter Five

First Study: Evaluation of DIY-Materials

In the previous chapter the different kingdoms and their associated sub categories provide a perspective that contributes to a better understanding of DIY-Materials. The cases included in the different sub-categories were chosen specifically to illustrate the common characteristics that all similar DIY-Materials share. In this chapter, the focus is on the evaluation instruments developed to examine the different cases and to collect data. Each instrument provides a specific type of data and the analysis of it validates the working Hypothesis **(WH2)**. The following chapters will build upon the evaluation parameters of this chapter and will open up new research questions to explore and delve deeper into the DIY-Materials theory.

5.1. Qualitative exploration

Once the whole categorization and subcategorization of the kingdoms was concluded, it became critical for the research to develop an instrument that allows a better understanding of each kingdom. This graphic instrument consent to find the different conditions pushing designers to produce a material.

This study began with the question of *why people decide to do their materials? What are the proper conditions that will allow a person with no scientific and structured knowledge of materials to embark on such an endeavor?* To answer these questions, the development of the instrument started with the definition of five topics which became recurrent during the study and categorization of the kingdoms. All possible variables were included in the five main topics grouped on the basis of similarity.

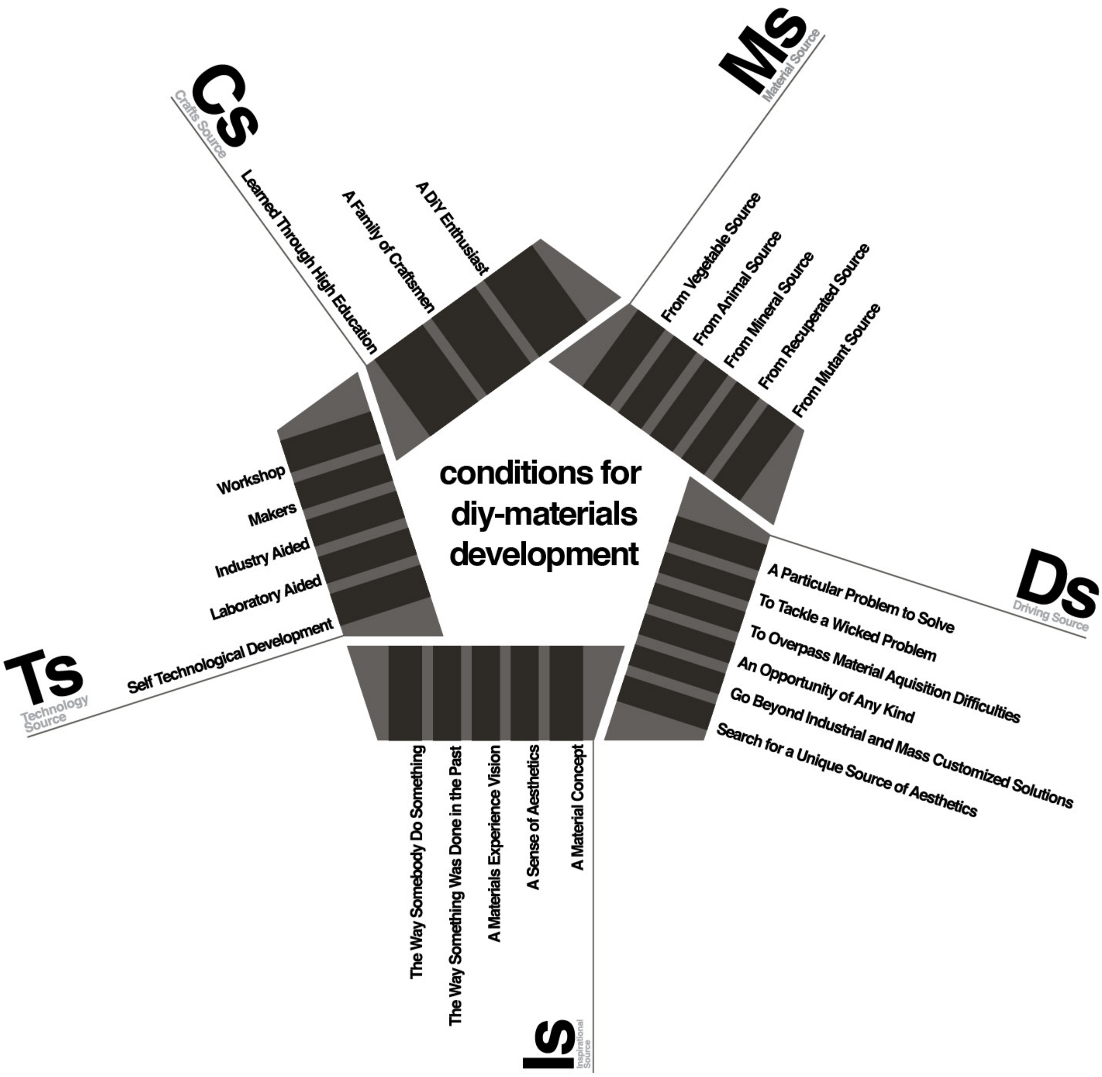
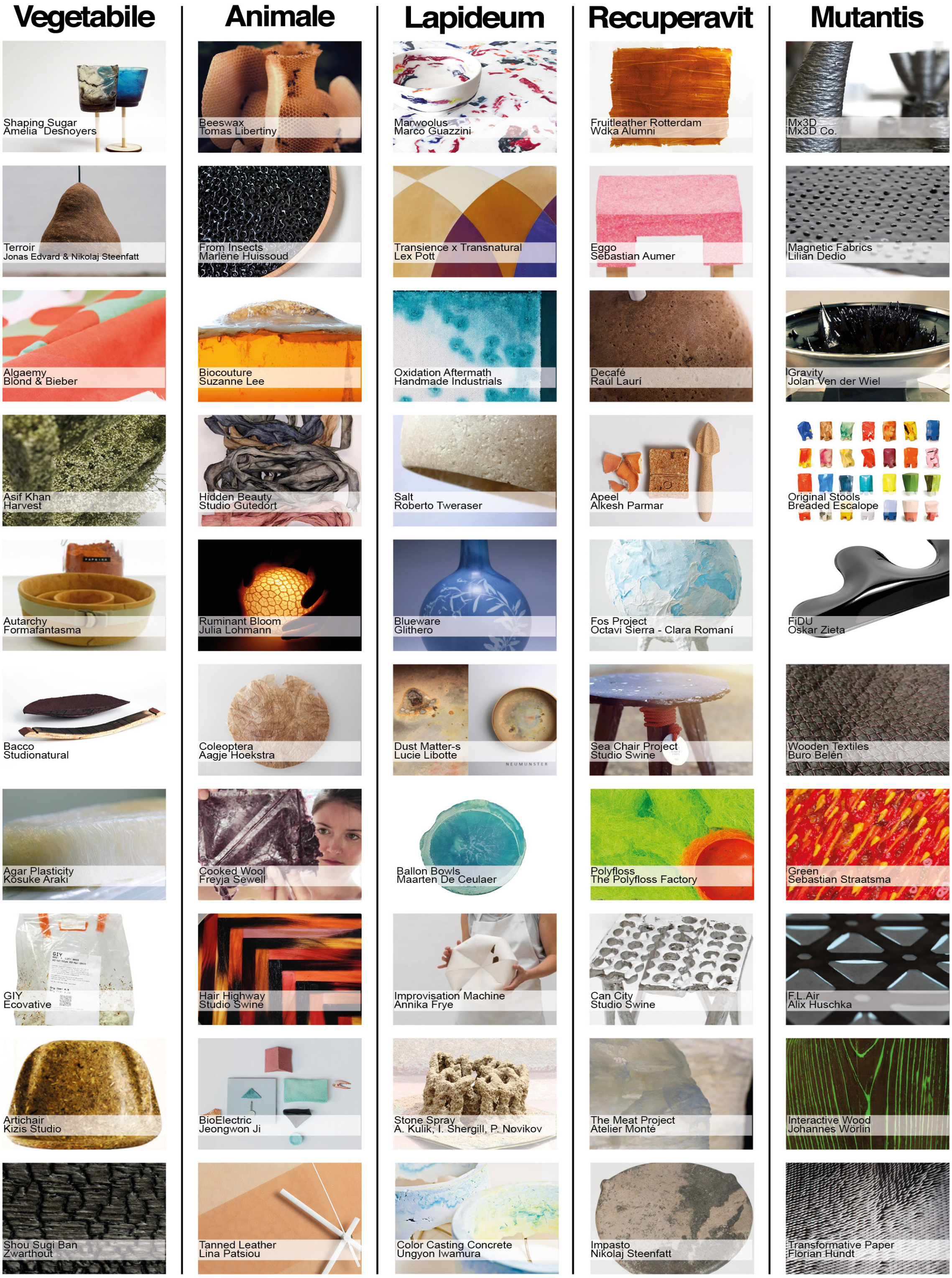


Figure 5.1
Pentagon instrument with the different motivations for DIY-Materials by designers.

5.2. Conditions that allow the development of DIY-Materials

The five main topics were named "sources" for better coherence and understanding. Each source presents different conditions. Each condition responds to the different motivations that push the designer to develop a material. The instrument has a pentagonal shape to provide a visual coherence within the kingdoms (Figure 5.1). All sources, together with the different conditions, are distributed to each side of the pentagon. This instrument was used in all different cases to gather information about the motivations every designer expresses to develop


Vegetabile
Shaping Sugar
Amelia Desnoyers
Terroir
Jonas Edvard & Nikolaj Steenfatt
Algaemy
Blond & Bieber
Asif Khan
Harvest
Autarchy
Formafantasma
Bacco
Studionatural
Agar Plasticity
Kosuke Araki
GIY
Ecovative
Artichair
Kizis Studio
Shou Sugi Ban
Zwarthout
Animale
Beeswax
Tomas Libertiny
From Insects
Marlène Huissoud
Biocouture
Suzanne Lee
Hidden Beauty
Studio Gutedort
Ruminant Bloom
Julia Lohmann
Coleoptera
Aagje Hoekstra
Cooked Wool
Freyja Sewell
Hair Highway
Studio Swine
BioElectric
Jeongwon Ji
Tanned Leather
Lina Patsiou
Lapideum
Marwoolus
Marco Guazzini
Transience x Transnatural
Lex Pott
Oxidation Aftermath
Handmade Industrials
Salt
Roberto Tweraser
Blueware
Glithero
Dust Matter-s
Lucie Libotte
Ballon Bowls
Maarten De Ceulaer
Improvisation Machine
Annika Frye
Stone Spray
A. Kulik, I. Shergill, P. Novikov
Color Casting Concrete
Ungyon Iwamura
Recuperavit
Fruitleather Rotterdam
Wdka Alumni
Eggo
Sebastian Aumer
Decafé
Raúl Laurí
Apeel
Alkesh Parmar
Fos Project
Octavi Sierra - Clara Romaní
Sea Chair Project
Studio Swine
Polyfloss
The Polyfloss Factory
Can City
Studio Swine
The Meat Project
Atelier Monte
Impasto
Nikolaj Steenfatt
Mutantis
Mx3D
Mx3D Co.
Magnetic Fabrics
Lilian Dedio
Gravity
Jolan Ven der Wiel
Original Stools
Breaded Escalope
FiDU
Oskar Zieta
Wooden Textiles
Buro Belén
Green
Sebastian Straatsma
F.L.Air
Alix Huschka
Interactive Wood
Johannes Wörlin
Transformative Paper
Florian Hundt

a material. The evaluation of each case using this evaluation instrument will be explained in section 5.4.

Figure 5.2
On the opposite page. All cases studied classified into five kingdoms: Vegetabile, Animale, Lapideum, Recuperavit and Mutantis.

5.2.1 Material Sources

The first topic or condition has been deeply explored in **chapter four** as it deals with the understanding of the different sources of a material. In fact, the first element of the instrument is named the Material Source. These sources are classified into kingdoms (Figure 5.2), and a full description of cases is available in the previous chapter and the appendix. The kingdoms will appear in the instrument named as material sources.

5.2.2. Driving Source

The case studies have shown that almost everybody who embarked on the challenge of creating its material is pushed by a particular interest instead of operating on a brief. All these interests that drive the designers were grouped in the second topic named the Driving Source

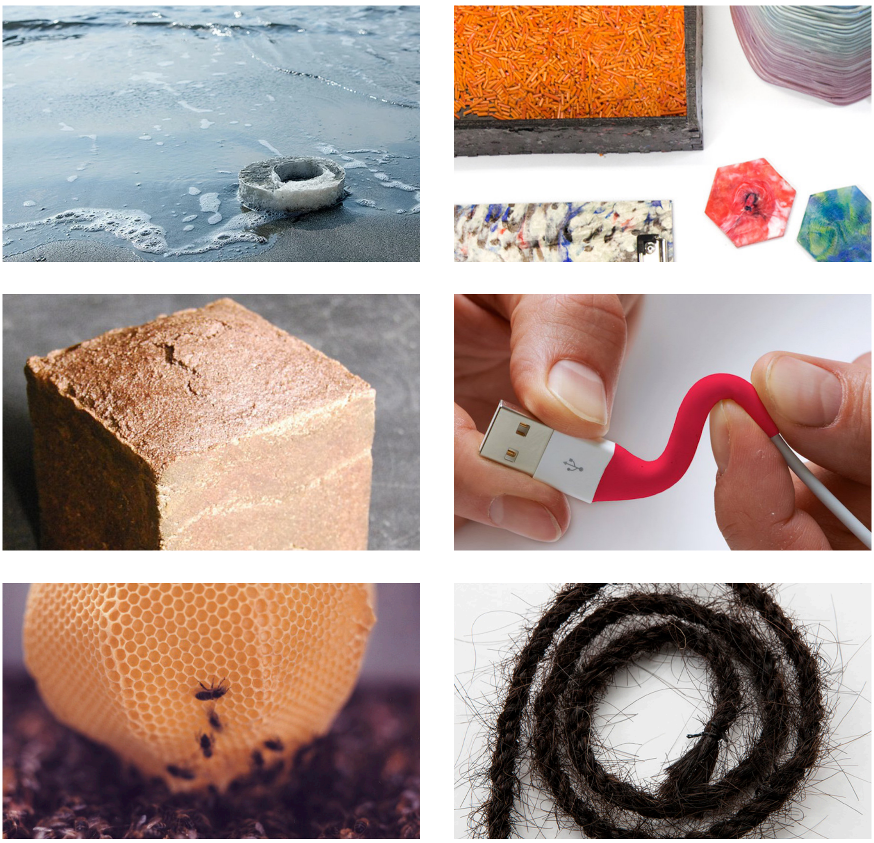


Figure 5.3
Driving sources examples in order from top left (a) Agar plasticity seek to replace plastics for packaging. (b) Precious plastic seeks to tackle the wicked problem of polymers garbage. (c) Bloodbricks seeks to build construction materials where is difficult to obtain bricks. (d) Sugru found an opportunity to fix and make products last longer. (e) Made by bees search unique production methods by co-creating with insects. (f) The new age of trichology, search aesthetics of human hair.

(Figure 5.3). Some cases have shown that the primary driver was the search to solve a specific problem (e.g., trying to build a product without screws or joints). Sometimes the driver was a way to help resolve a problem in modern society (e.g., too much waste on the planet, extreme consumption of resources, etc.). Other designers are driven by the fact that industrial materials are sometimes difficult to obtain, especially outside Europe, the U.S. or East Asia. Some cases encounter an opportunity to create their own business or to help a particular community. Some others have manifested that their driver was the desire to make a specific statement or message to humankind. There are also other designers stating they want to go beyond the industrial and mass customized solutions of our actual era. Finally, some designers said that they are driven by constant research for a unique source of aesthetics.

5.2.3. Inspirational Source

This condition may be subject of debate, as it is pushed by different types of sources of creativity. In other words, Material Science does not tend to get inspired by any sources discovered in the studied cases. As Materials Sciences have other drivers more related to materials performance or finding a material surrogate for another source that is either expensive, unsustainable or nonrenewable (Rognoli & Levi, 2005 p.16), there is little room for creative inspiration. The inspirational sources found during the study are described as follows and illustrated in figure 5.4.

A Material Concept

Designers are always willing to develop a concept. Without a concept, the perceived design is a weak solution to a problem without any added value. It is evident in the cases studied that some were intended to be understood as a material concept. That means that no specific properties are being characterized or tested, but the message behind them is enough to produce the concept.

A Sense of Aesthetics

Many designers are experimenting with the material sources inspired by their senses, and, therefore, a constant search for a proper color palate among the material samples, or the research of a pure shape or even study of particular patterns that can be imprinted into the material count as a source of inspiration.

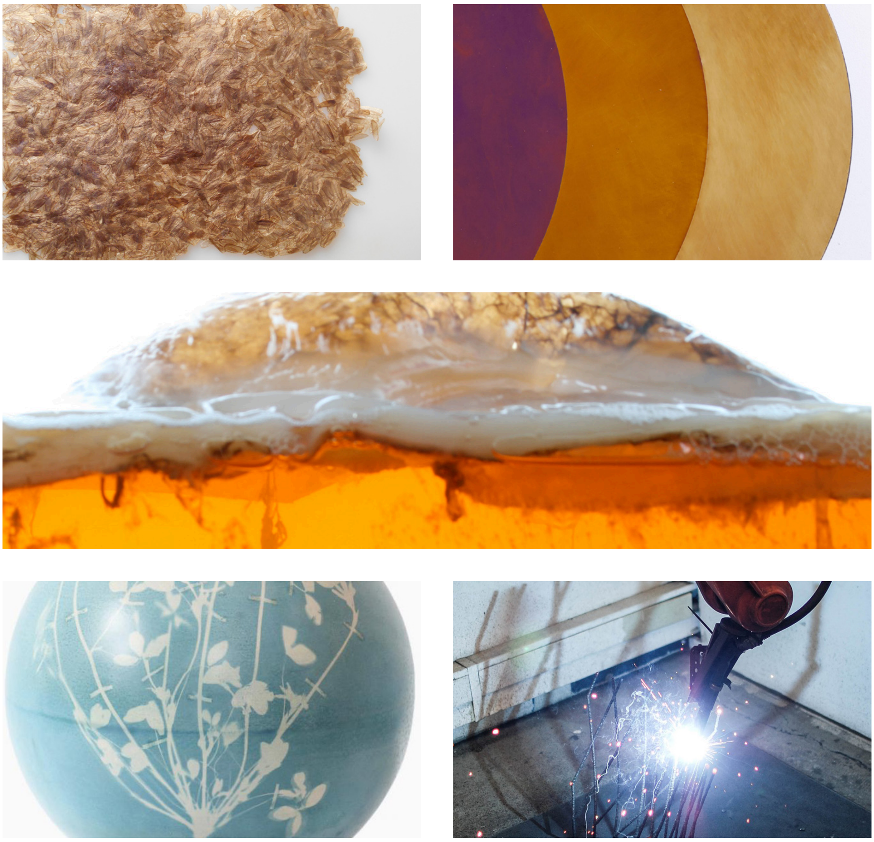


Figure 5.4
Inspirational sources examples in order from top left (a) Coleoptera inspires from a material concept by using dead parts of insects. (b) Transcience X gets inspired by the colors of oxidation.
(c) Biocouture receives inspiration from bacteria to produce garments. (d) Blueware Vases gets inspiration from traditional analog photography. (e) MX3D Gets inspiration from automotive welding robots and their movement.

A Materials Experience Vision
Some designers are more involved with the relationships that exist between the materials, the people, and some particular practices. This idea is known as Materials Experiences Framework (Giaccardi & Karana, 2015). As is evident in some cases, this counts as a source of inspiration. When the material development is strongly linked with an application, a materials experience vision is clear since the beginning of the project.

The last two sources of inspiration encountered in this phase of the research, deal with either the way something is done in the past (e.g., a lost craft) or the way somebody has been doing something since a long time (e.g., a chef cooking, a grandmother knitting, etc.).

5.2.4. Technology Source
In this source, using a self-developed practice may require further maturation and engineering tuning before scaling up a material like

any other present in the market. For that reason, designers seek help from different fields to achieve their goals. Some designers turn to laboratories for chemists or biologists to aid them with scientific knowledge to deal with unknown sources such as bacteria or fungi. Some others appeal to the maker's movement to hack any available three-dimensional machine and experiment with it. Many designers use their workshops to develop any possible technology that can help to achieve the goal, and there are also a few that are inside a particular industry that believes in their ideas and assists in the development. In this source, some of these scientists and engineers appear as passive actors compared with the designers but are crucial to providing specific knowledge during the different phases of the material development (Figure 5.5).

In this section also appears a concept essential for the DIY-Materials theory, and it is related to the practices. Two types of practices started to emerge by studying the different cases: one group is formed by the technologies and practices to find and obtain a material source, and

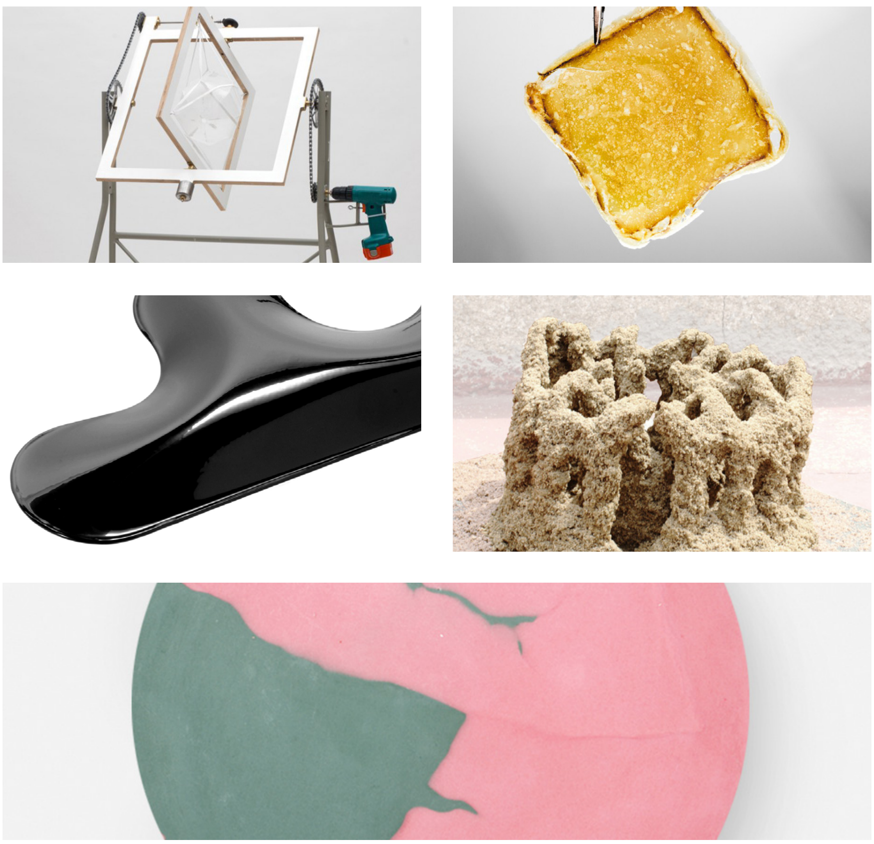


Figure 5.5
Technology sources examples in order from top left (a) Improvisation Machine DIY rotational molding. (b) The Growing Lab works in a lab to obtain mycelium. (c) FiDU developed a blow molding technology. (d) Stone spray Hacked a 3D printer to inject sand. (e) KIVI used traditional RAM compression method for ceramics.

the other group is related to the techniques and practices to develop a material. Designers seeking a material to produce, interact in a multidisciplinary approach and behave, depending on the challenge a little bit like a farmer, or as a chef. They try to understand specific knowledge like an alchemist or as a scientist, or even elaborate machinery and twist manufacturing processes trying to behave like an engineer. This affirmation is not intended to argue that designers are the ones that know it all. In fact, designers lack a structured learning curve based on the nature of the discipline and are never able to comprehend and solve specific problems like each of the professionals mentioned above. Nevertheless, the non-linear way of thinking by designers allows them to enter into a discipline very easily and mediate different topics, exchange ideas and grasp insights to develop and innovate, as in this case, with a material.

5.2.5. Craft Source

There is a strong connection between design and crafts. Although some design schools or specialization programs have recently begun to focus on more intangible means to design, others are rooted and preserve the link between the act of design and the physical creation of things. Many cases have shown a particular ability to create with their hands, developing not only the materials but also setting up the whole experimentation environment. Some projects come from a family of craftsmen, and as a result, the hands-on project is naturally a part of their research for a material. There is also room for a DIY enthusiast who, by navigating in the sea of the internet and obtaining open access to technology, together with a keen interest in a material source, achieves a particular resource that is worth analyzing (Figure 5.6). In this final source, it is visible how in all cases, the ability and disposition to do things with the hands is taken for granted. During the evaluation, the knowledge of a designer in a particular craft or the improving of a technique during the material development becomes relevant, not because the designer makes it explicit, but because of the way he or she tells the story. In this section is clear how a general knowledge of materials and their properties, the different behaviors and the manufacturing processes are fundamental, even if the designer is not fully aware of them. All designers examined with this evaluation instruments, are new craftspeople. None of the above mentioned suggested a theoretical, service-oriented or digital approach. This particular insight became essential for the DIY-Materials theory formulation.

Figure 5.6
Craft sources examples in order from top left (a) Transformative paper started as a project in the IMD Offenbach. (b) From Insects resulted as the designer belongs to a family of beekeepers. (c) Memorabilia factory comes from a self-production enthusiast.

5.3 Method for data collection

The different cases collected belong to different origins. Some materials were published in different media, some others were showcased in design exhibitions and some others were presented at conferences and special events. This great quantity of mixed data needed a methodical strategy that allows the organisation of information in relation to the different materials and also provide guidance on how to analyze it. Five strategies for triangulation of information (Patton, 1990 p. 187) supported the gathering of information from each case, and all this collected information serves not only for the study conducted inside this doctoral research but also to build a database of the different cases (see www.diy-materials.it). For all one hundred cases observed, at least four of the following strategies were applied:

-Interviews/people´s statements (when possible): Transcription of interviews.
-Observation: Videos, Field Notes from direct observation.

-Document Analysis: Letters, Emails, Facebook Posts.
-Archival Records: Newsletters, Articles, Images.
-Artifacts: Prototypes, Materials Samples, Products developed with the Materials

Once the various cases were sorted out and divided into the different kingdoms, a systematical analysis of data became necessary. For that purpose, a set of initial questions for case analysis emerged. This allows having a hierarchy of relevant information. The more complete cases provide a better understanding not only of the material but also the shared similarities between materials of the same type. This was the first building block to propose a sub-categorization inside each kingdom as seen in **chapter four** and provide initial data to highlight shared aesthetical qualities as seen in the second study in **chapter six**.

5.3.1. Relevant Data

-Which Kingdom(s) does the material belong to? -Is there any visible process?
- Has the designer shared the recipe or the development process?
- Does the different media show the properties and qualities of the developed material (Technical & Expressive-Sensorial)?
-The different media show the possible outcomes and can applications be developed further?
-Is there any associated Life Cycle considered?

Independent from the hierarchy of information provided by the cases, the research for all possible data that could provide useful information became crucial. A check-list with the different data to search and collect on each case became necessary to work with all the cases (Figure 5.7).

5.3.2. Collected Data

-Name of the Material (if it exists).
-Name of the person (designer) or studio.
-Location (country of origin of the studio or the designer).
-Purpose (Experimental, artistic or commercial).
-Time taken to develop the material.
-Drivers for the development of the material.
-Problems and challenges during the experimentation (any information regarding the experimentation process from which is possible to

obtain difficulties during the development and the possible solutions).
-Advantages of the material (in terms of properties and qualities).
-Open Sourced or Restricted. (possible IP protection or patents).
-Recipe (step by step guide and production techniques).
-Recipe (list of ingredients).
-Environmental Impact (measurements in terms of Cradle to Cradle, Life Cycle Assessments, etc.).
-Selling quote (Slogan or phrase which describes briefly the material).
-Process Images (if any).
-Key Shot of the sample.

5.3.3. Triangulation Sessions

To agree on the accuracy of the collected data, the whole materials experience research team of Politecnico di Milano was invited to participate in two informal sessions with the aim of (1) presenting the

Figure 5.7
Document used for the triangulation sessions.

POLITECNICO MILANO 1863

DIY MATERIALS CASE STUDIES //
IMPORTANT NOTE. All data collected is taken either from their owner's website, publications or interviews)

Case 20.
//Name of the Material
Honey Comb Material
//Name of the Person (designer) or Studio
Tomas Libertiny-Studio libertiny
//Location
The Netherlands - http://studiolibertiny.com
//Experimental, artistic or commercial purpose
Experimental Arts
//Time developing the material
10 Years
//Drivers for the development of the material
Exploration of the relationship between nature and technology. The results are conceptual and physical strategies in design and construction of sculptural objects and installations.
//Troubles during the experimentation
Time consuming as bee's have their own time
//Advantages of the material
Uniqness of shape
//Open Sourced or Restricted
Restricted
//Recipe (step by step & Production Techniques)
Avaliable
//Recipe
Non Availabe
//Environmental Impact (CTC, LCA)
CTC
//Selling quote
"Made by Bees"
//Process Images
Yes
//Key Shot of the sample
Yes
----

different cases collected, sorted by kingdoms and (2) providing sheets including all the relevant data collected in a checklist format. Each participant was requested to search in the different media all possible information of a given list of materials. If the results of the small research made by a participant match with the ones previously collected, then it would be considered a valid input.

The research team at the time of the meetings included the supervisor and co-supervisor, three Ph.D. Candidates and three Master students.

The sessions served to tune up the information research and to see possible gaps in the different cases. In some cases, there was the need to search for more information and reevaluating the case with the evaluation instruments afterward. The previous set of questions, although it was developed with the idea to be an internal document to check for the accuracy of the information gathered, served as the starting point for the development of the DIY-Materials datasheets, explained in the outcomes section of **chapter seven**. By observing the amount of information that could be organized on a single page, the idea to develop a datasheet allowing to show information of each

Figure 5.8
DIY-Materials datasheets containing all relevant information.

material became clear. A test sheet was developed containing all the information gathered from a particular material (Figure 5.8) Those sheets were shared with the participants of the third and fourth study to obtain feedback. Some minor adjustments appear, but the format became the standard datasheet for the DIY-Materials Theory as explained in **chapter nine**.

5.4. Evaluation instruments

5.4.1. Conditions pentagon instrument

With all data collected, the path to analyze and evaluate the different cases in terms of the five conditions began. The pentagon instrument became an element for analyzing information. For each case, a pentagon is marked depending on the different sources that interact in the development of the material (figures 5.9 1-5). For instance, when studying a DIY-Material, the first step begins by defining the material source, **(A)** that can belong, to one or more different kingdoms. The second step consist on analyzing what is driving the designer to embark on the material development **(B)**. In this part, it became visible that the cases inside a particular kingdom share similarities regarding what drives the development of the material. Third step begins by studying the source of inspiration **(C)** for the designer to perform the DIY-Material development. In many cases, designers get inspired by the way somebody does something. For example, in the two cases of sugar glass and shaping sugar (Figure 4.10 in **chapter four**), the designers said that they were inspired by the traditional Murano glass making process from the Venetians. Another example comes from studio Swine (Figure 4.14 b on **chapter four**) who affirm that they were inspired by the old tradition of the Chinese culture to collect, clean, align and cover with resins and human hair to produce a material and a collection of objects that resemble the ones made from tortoiseshell or ivory. The Fourth step begins by analyzing which type of technology that supports the material development **(D)**. Finally, in the Fifth step, we analyze the relationship between making a material and the ability of the designer to perform such project(s) **(E)**.

All cases were evaluated using the same instrument. Multiple entries inside each condition's group are possible, as the aim of the instrument is to extract as much information possible from any case.

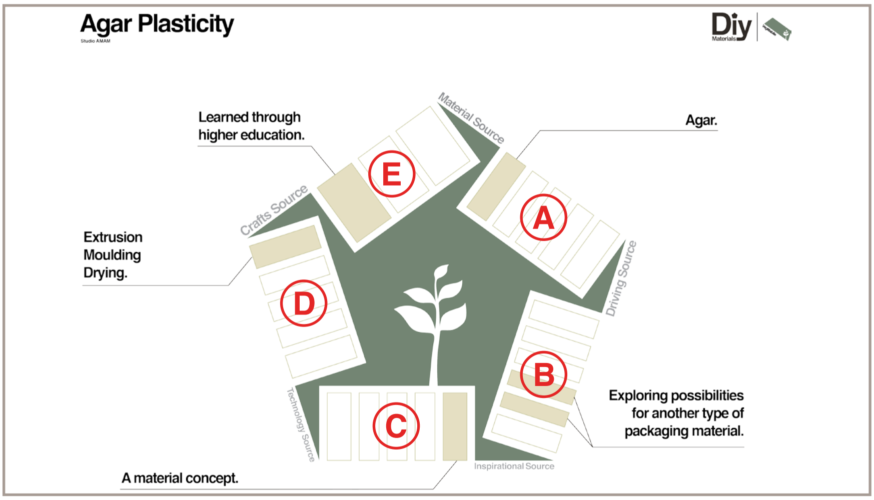


Figure 5.9 (1)
Conditions pentagon instrument example for a case belonging to Kingdom Vegetabile.

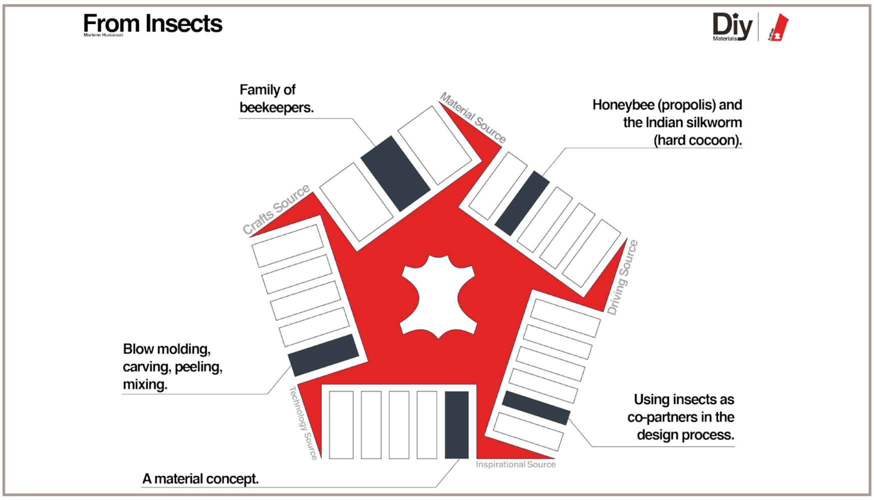


Figure 5.9 (2)
Conditions pentagon instrument example for a case belonging to Kingdom Animale.

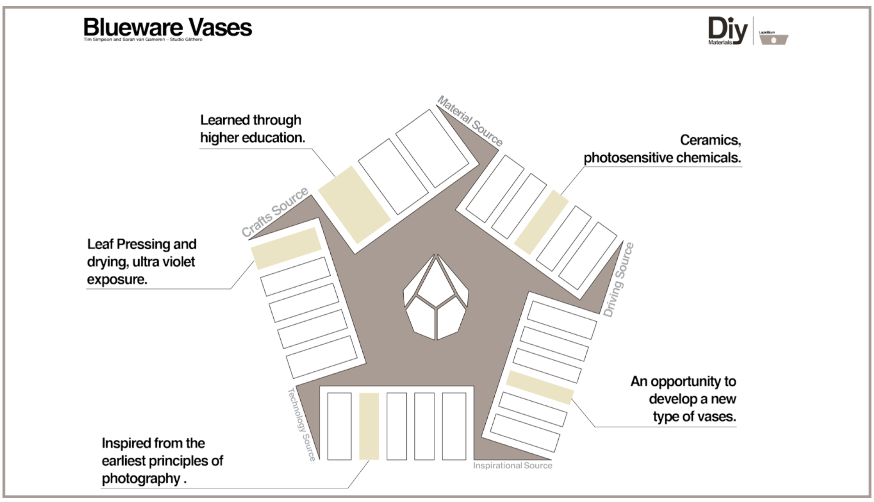


Figure 5.9 (3)
Conditions pentagon instrument example for a case belonging to Kingdom Lapideum.

Figure 5.9 *(4)*
Conditions pentagon instrument example for a case belonging to Kingdom Recuperavit.

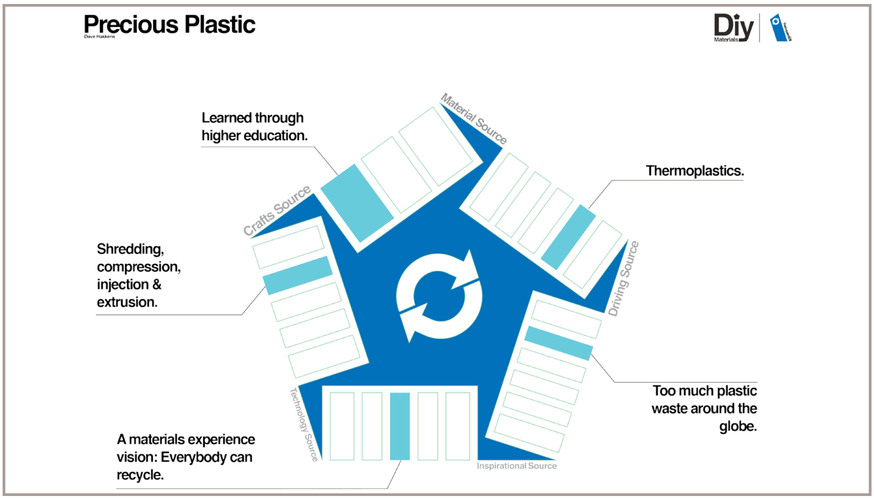
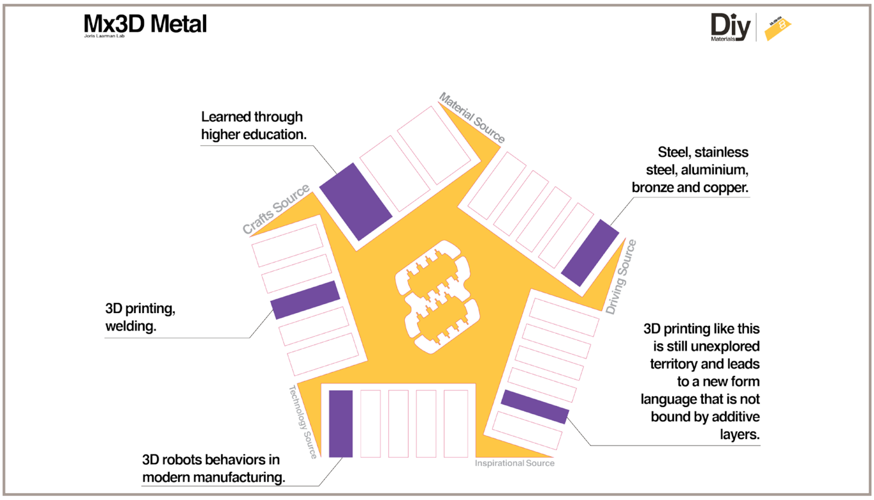


Figure 5.9 *(5)*
Conditions pentagon instrument example for a case belonging to Kingdom Mutantis.



5.4.2. Weight of conditions instrument

All the different information gathered from the different cases came from random sources. Sometimes from the designer's site, an interview either to a design related magazine or to the researcher. Measuring the significance of the established conditions for the different cases became crucial. In other words, it was necessary to measure if the different conditions for a DIY-Materials development were not only mentioned but also with what degree of intensity. These include questions like, How proud is the designer about the source he or she selected, or how vital was the source of inspiration and so on. The different patterns observed with this second instrument provide additional information allowing the formulation of a research question **(RQ2)**. In this radar type of charts, it is possible to see this

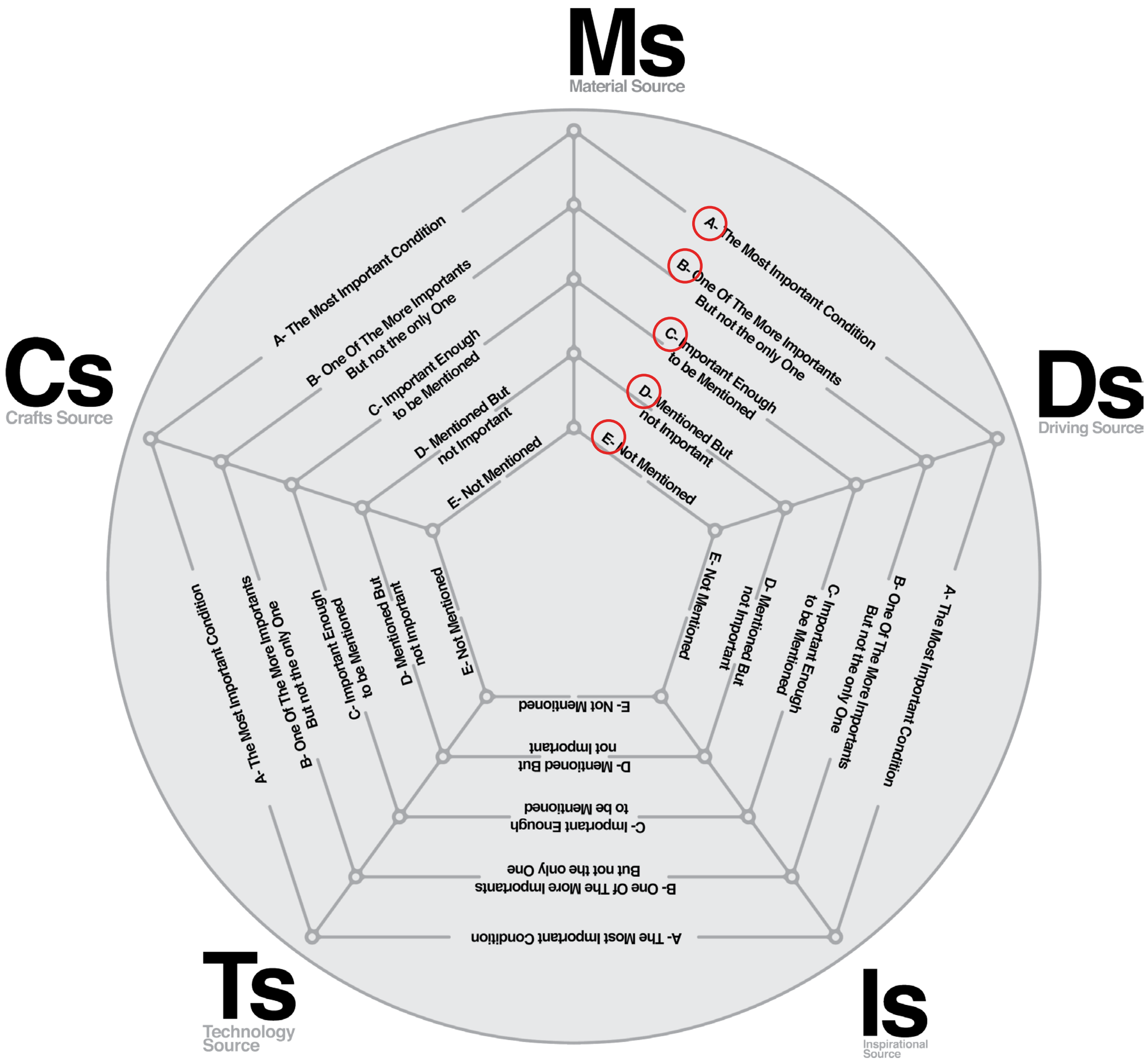
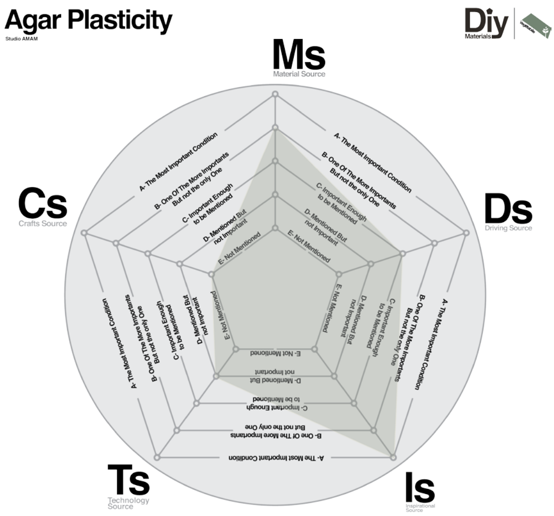


Figure 5.10
Weight of conditions instrument.

hierarchical intensity of data. Each case was measured in terms of relevance given to a particular condition during the triangulation of data process. Five levels defined to measure the intensity of each condition started with **(A)** The most important condition. **(B)** One of the more important conditions, but not the only one. **(C)** Important enough to be mentioned. **(D)** Mentioned but not important. **(E)** Not mentioned (Figure 5.10). By plotting each case inside a kingdom with this instrument (Figure 5.11), and then overlapping all cases of the same kingdom, some patterns and tendencies began to appear.



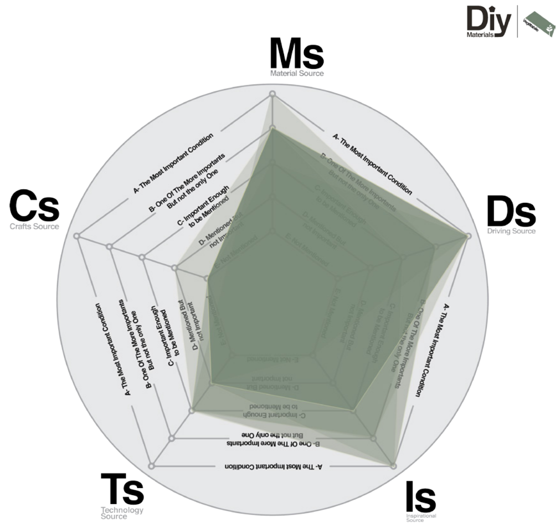


Figure 5.11
Left: (a) Weight of conditions instrument on a case inside Kingdom Vegetabile.

Figure 5.12
Right: (b) All cases from Kingdom Vegetabile evaluated and overlapped.

From the pentagon's instrument explained above, information relevant to understand behaviors and trends inside each kingdom was obtained. For instance, inside Kingdom Vegetabile the driving source weighted more than the other four sources (Figure 5.12). This tendency could mean that all the different cases classified inside this kingdom pay particular attention to the reason that drives the project.

In the Kingdom Animale plot, it is visible how the driver source also plays an important role, but there is a tendency to rely on a particular technology source to aid the material development (Figure 5.13 a).

Similar to what happens in the previous kingdom, in Kingdom Lapideum there is a strong relationship between the material source and the technology to transform it. As said in the definition of this kingdom, almost all cases expressed an active link to crafts probably because these types of materials have a long tradition in our material culture (Figure 5.13 b).

Plotting Kingdom Recuperavit cases, the balance between what drives, what inspires and which technology is necessary to appear relatively balanced. Almost in all cases under this category, there was a connection between the driving source and the inspirational source. For example, if the designer expressed the intention to tackle a serious problem, the material concept and the material experience vision were strongly connected with this purpose (Figure 5.13 c).

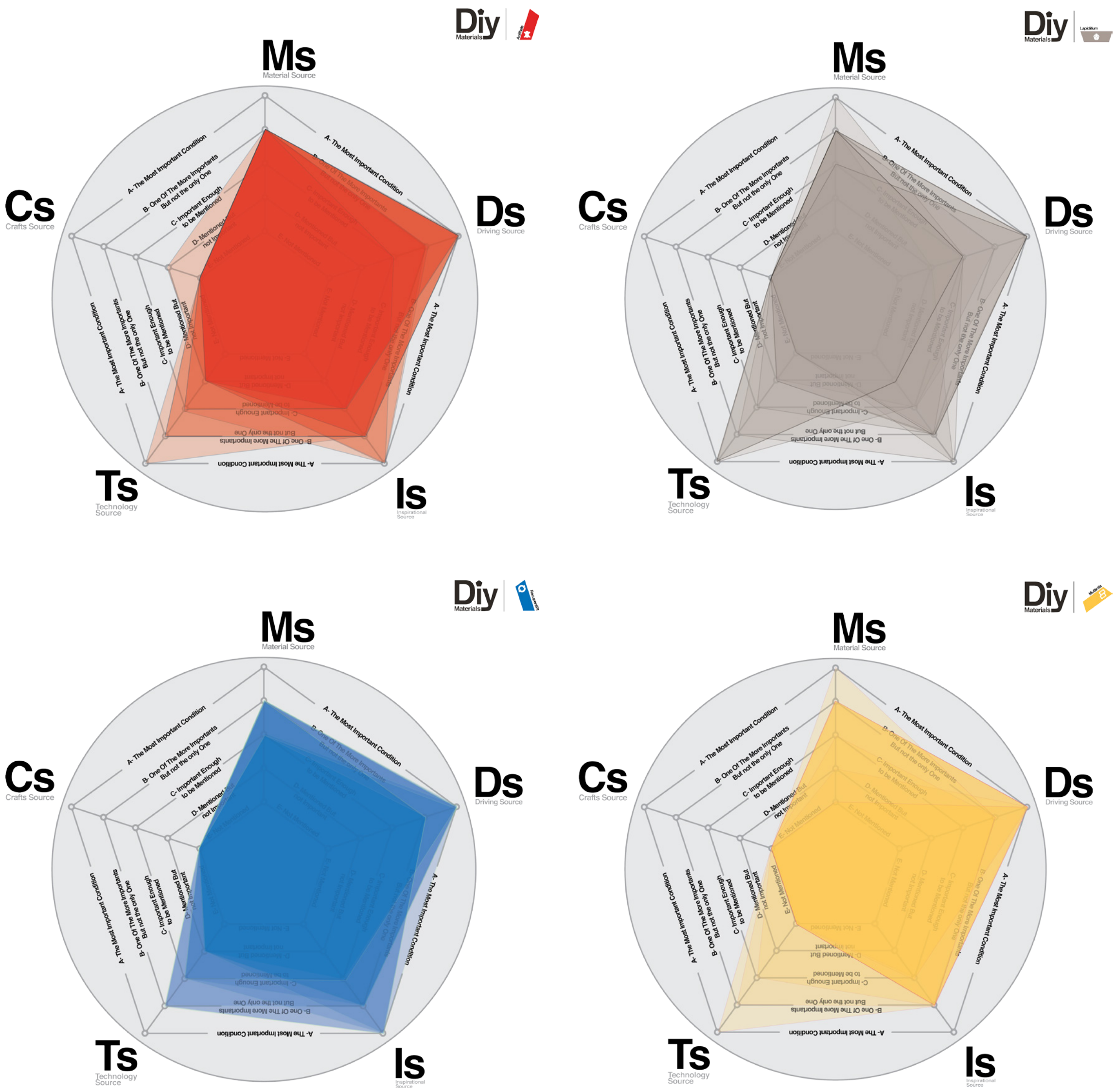


Figure 5.13
(a) Top left: All cases from Kingdom Animale.

(b) Top right: All cases from Kingdom Lapideum.

(c) Bottom left: All cases from Kingdom Recuperavit.

(d) Bottom right: All cases from Kingdom Mutantis.

In the majority of cases inside Kingdom Mutantis, it became visible how vital it was to stress the technology that supports the material, regardless of the technology type there is. Particular attention is given to show the process and collaborations between the designer and other actors to achieve the materials result (Figure 5.13 d).

After analyzing and plotting all cases, it was observed that although all of the cases showed an ability to work with the hands, almost none of the one hundred cases mentioned anything related to their ability to

craft a material. In the beginning, such insight suggested that this adverse outcome in the plot could lead to the removal of the entire condition group from the pentagon evaluation instrument as there was no data collected. However, after various debates around the interpretation of this data, it became clear that the reason to not mention such abilities means that in almost all cases, there is a strong background and education on crafts. Reanalysing the data in the light of the educational institutes attended by designers, it became clear that a high percentage of these were formed by designers who attended universities or design schools. Many have learned to do the project influenced by the University, or Design school attended (e.g., Royal College of Art, Design Academy Eindhoven, IMD Offenbach, Central Saint Martins among others). These schools are well known to have experimental material development as a fixed track of the curricula. More of the half of the cases studied started as a graduation project.
With the evidence that crafts ability is mandatory, but mostly taken for granted, the doctoral research opened the doors to perform a study to test if to develop a material from the design domain, the ability to craft could determine the success or failure of the project. This became study three in **chapter seven** and study four in **chapter eight**.

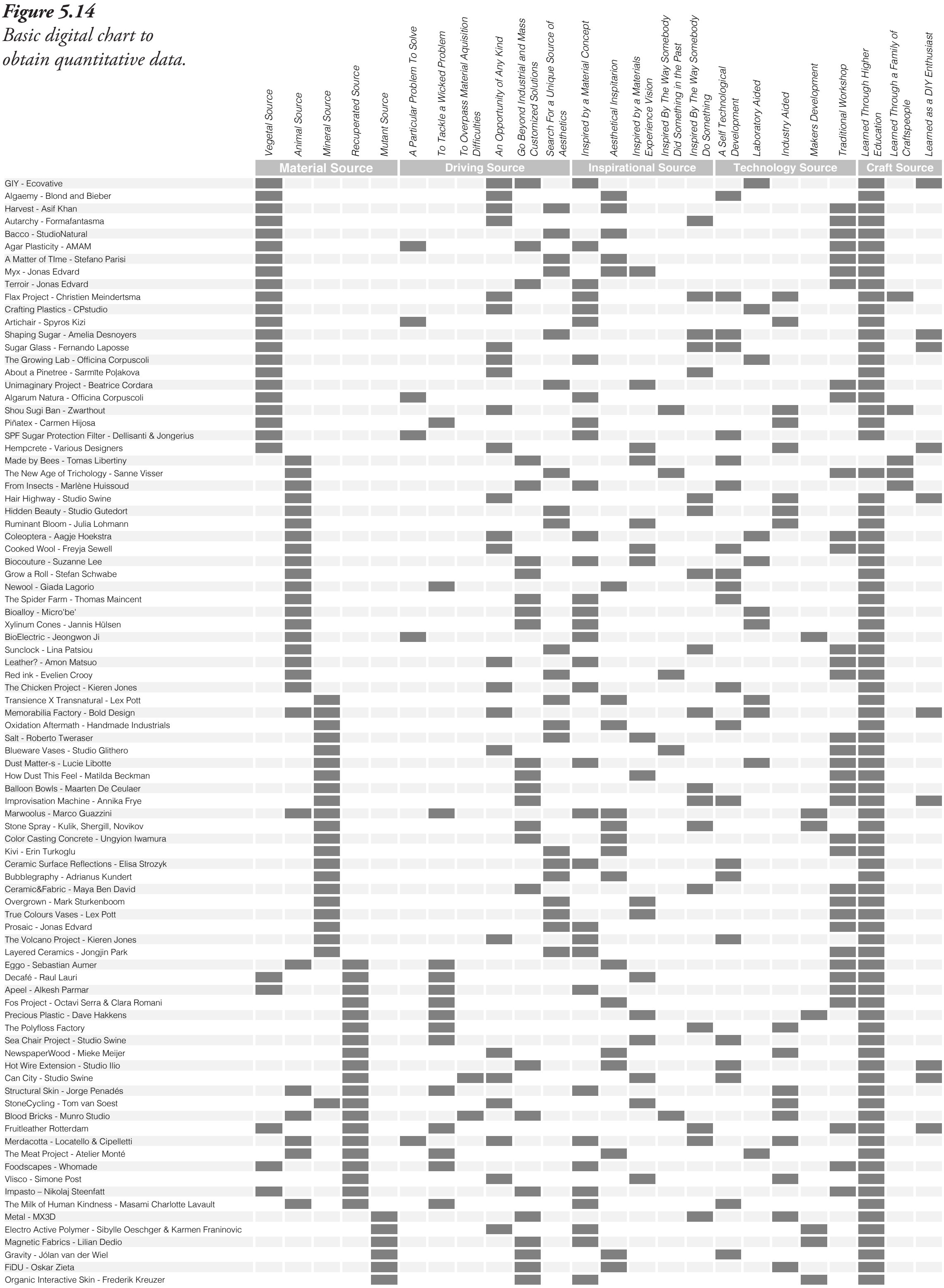
5.5 Quantitative analysis

All the pentagons and radar charts contain a considerable amount of data that was extracted from every single DIY-Materials case and from the relationships between the case and its kingdom. However, this amount of data being qualitative in its nature, could not provide information and insights for discussion. The information was plotted into a basic digital chart. For every condition marked in the pentagon, each case will receive a value of one (1). For every condition that is not marked, each case will receive a value of zero (0) (Figure 5.14). This simple algorithm showed some numbers allowing to transform them into graphic data. The visualization of this data showed different tendencies and behaviours between the kingdoms.

5.5.1. Data Analysis

With the different values transformed into quantitative data, three graphics show relevant information. The first graphic evidence provides the different tendencies of DIY-Materials regarding the driving source (Figure 5.15).

Figure 5.14
Basic digital chart to obtain quantitative data.



F.L.AIR - Alix Huschka					■					■		■				■				■		■		
Interactive Wood - Johannes Wöhrlin					■						■		■	■						■		■		
Paralightskin - Pohlmann, Schwarze, Wöhrlin					■						■		■	■						■		■		
Transformative Paper - Florian Hundt					■						■		■	■							■	■		
Original Stool - BreadedEscalope					■					■				■			■					■		
The Creative Factory - Thomas Vailly					■					■				■			■					■		
Dyed Wooden Textiles - Elisa Strozyk					■					■				■							■	■		
Synthetic Aesthetics					■				■			■						■				■		
Sugru - Jane Ní Dhulchaointigh					■			■	■					■				■				■		
Conductive ink - OpenMaterials					■					■		■								■		■		■
Green - Sebastiaan Straatsma					■						■		■				■					■		
Wooden Textiles - Buro Belén					■					■		■							■			■		
Muscle Sensors Textile - Jessica Smarsch					■	■								■		■				■		■		
IRE Möbel - Anna Vallgarda					■					■		■								■		■		
Generative Scarves - Convivial					■					■				■						■		■		
Total of Cases	27	27	22	20	21	7	15	3	27	33	25	39	24	26	5	20	25	13	18	14	36	100	5	11
Percentage of all cases	26%	27%	21%	20%	20%	7%	15%	3%	26%	31%	24%	38%	24%	24%	5%	20%	25%	13%	17%	13%	35%	98%	5%	10%
Total cases Kingdom Vegetabile	22					4	1	0	10	3	6	10	5	2	1	5	5	3	4	0	9	21	2	3
Total cases Kingdom Animale		19				1	1	0	5	7	5	9	1	4	2	4	7	4	3	1	5	17	3	1
Total cases Kingdom Lapideum			21			0	1	0	3	7	10	6	7	4	1	5	5	3	0	2	13	21	0	2
Total cases Kingdom Recuperavit				20		1	12	2	5	3	0	6	5	6	1	3	4	1	7	1	7	20	0	3
Total cases Kingdom Mutantis					21	1	0	1	3	13	4	8	6	9	0	3	4	2	3	10	2	21	0	1
Percentage by Kingdom Vegetabile						18%	5%	0%	45%	14%	27%	45%	23%	9%	5%	23%	23%	14%	18%	0%	41%	95%	9%	14%
Percentage by Kingdom Animale						5%	5%	0%	26%	37%	26%	47%	5%	21%	11%	21%	37%	21%	16%	5%	26%	89%	16%	5%
Percentage by Kingdom Lapideum						0%	5%	0%	14%	33%	48%	29%	33%	19%	5%	24%	24%	14%	0%	10%	**62%**	100%	0%	10%
Percentage by Kingdom Recuperavit						5%	**60%**	10%	42%	15%	0%	30%	25%	30%	5%	15%	20%	5%	35%	5%	35%	100%	0%	15%
Percentage by Kingdom Mutantis						5%	0%	5%	14%	**62%**	19%	38%	29%	43%	0%	14%	19%	10%	14%	48%	10%	100%	0%	5%

Analyzing the driving source.

From this graphic it is possible to see how in Kingdom Vegetabile, the majority of cases were driven by an opportunity of any kind. The tendency inside this kingdom moves toward an opportunity to grow, farm or use bio based elements with autonomy. The majority of cases showed an intention to replace another material by a self-made biopolymer and applying to a particular object of the designer's own interest. Similar trend appears when looking at Kingdom Animale.

However, a different trend appears in Kingdom Lapideum, where more than the 40% of the cases expressed an intention to search for a unique source of aesthetics. Many of the different cases inside this kingdom focused on the development of different surface finishes rich of textures and colour combinations.

When analysing Kingdom Recuperavit it is possible to observe that around the 60% of the cases are driven by the idea to tackle a wicked problem such as finding more environmentally friendly solutions, recuperate waste from different sources and enhance social awareness of the problems of the misuse of materials.

When it comes to Kingdom Mutantis, it is possible to find also in this graphic how more than the 60% of the cases manifested in the idea to search for an alternative to go beyond industrial and mass consumption solutions. Either proposing a new materiality or a blend in the interaction between the material and a specific technology. Similar trend happens to many cases inside kingdom Animale where almost 40% expressed the same intention also by presenting a new materiali-

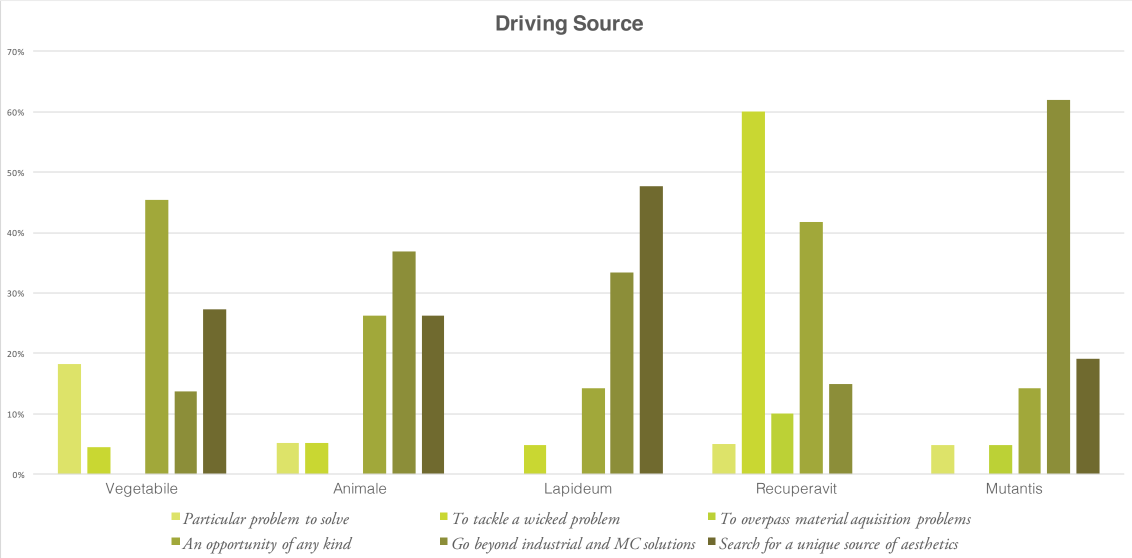


Figure 5.15
Weight of conditions for the driving source divided by kingdoms.

ty. Other cases inside this kingdom showed revealed similar results to what happened in Kingdom Vegetabile - a tendency to search for new opportunities to develop products and search for new aesthetics both at 28%.

An interesting insight inside this graphic shows how only a few materials from all the five kingdoms seek a particular problem to solve. This is an interesting fact as designers are nowadays more engaged in finding opportunities instead of solving problems.

Analyzing the inspirational source.

When it comes to understanding the different elements that inspire designers to perform a materials development, it is possible to encounter a series of characteristics inside each kingdom (Figure 5.16).

45% percent of the cases analysed inside Kingdom Vegetabile were inspired by a material concept. This means that in all of these cases a particular inspiration from some natural resources or the idea to bring elements from a particular element in nature led to a concept for the specific development.
A similar trend occurs in Kingdom Animale where almost 50% of the cases turn to nature as the inspirational resource and formulate a concept for a material development.

While in the first two kingdoms the tendency goes towards a material

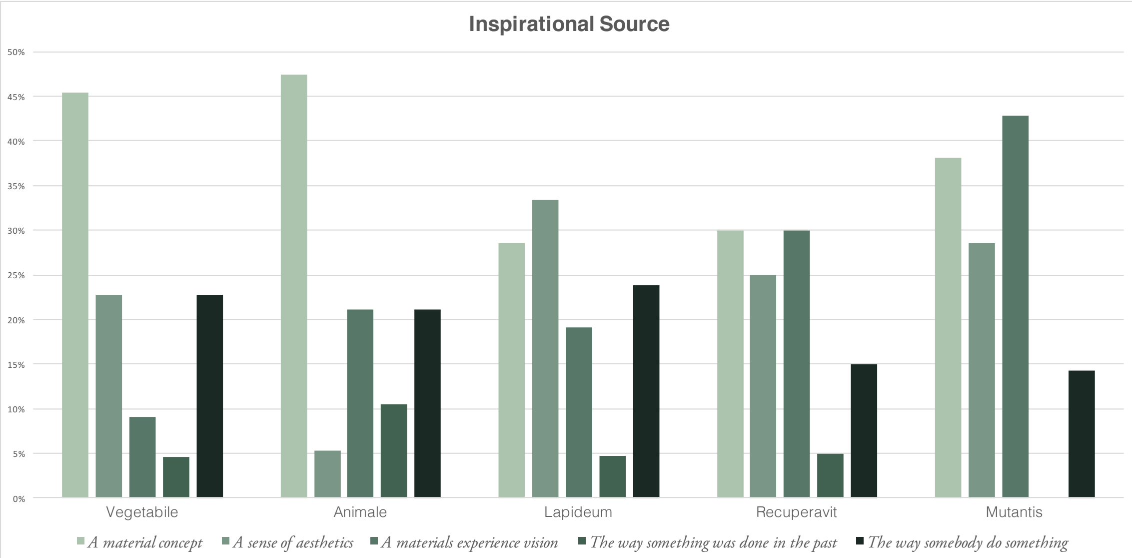


Figure 5.16
Weight of conditions for the inspirational source divided by kingdoms.

concept, in Kingdom Lapideum it is possible to see another growing inspiration trend in terms of aesthetics (33%). This is strongly connected with the previous graphics where the driving source is also a research for new aesthetics. Here, the designers explore with a high level of sensorial sensitivity, the different material qualities enhancing them in their material creations. Another visible trend inside this kingdom takes inspiration from the way somebody does something. This means that in many cases repurposing a particular craft in the material development is key for the material development (24%).

Looking at Kingdom Recuperavit, it is possible to see three main inspirational sources: a material concept (30%), a sense of aesthetics (25%), and a material experience vision (30%). This last inspirational source occurs when the material is developed for a specific application. When the designers have this idea in mind then it is possible to say that they are inspired by a materials experience vision.

Kingdom Mutantis reflects similar behaviours in terms of inspirational sources, but with a slightly high percentage: a material concept (38%), a sense of aesthetics (29%), and a material experience vision (43%).

In all kingdoms it is possible to see cases where inspiration from the way something was done by somebody else or the way something was done in the past is a common trend. This trend validates the hypothesis that DIY-Materials are constantly being inspired by different crafting practices, the designers get inspired by them and repurpose into new crafts.

Analyzing the technology source.

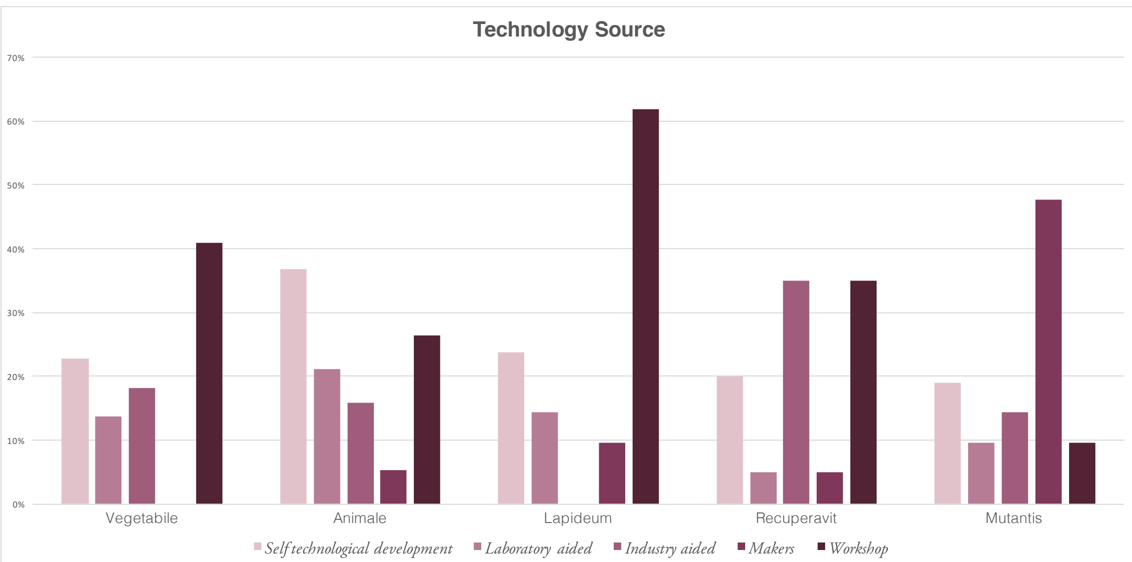
The last graphic where the different technology sources are measured shows the diversity of means to develop a material when those are classified into kingdoms (Figure 5.17).

In Kingdom Vegetabile, there is a tendency towards a traditional workshop aided development. This means that standard tools and low technologies allowed a development of many different cases (40%).

Kingdom Animale requires a higher level of technological development. For that matter, DIY tools specifically developed to obtain the desired material result are constructed by the designers (37%). Some laboratories get involved in the development of these materials as they deal with organic matter (20%). This form a higher percentage amongst all kingdoms.

Kingdom Lapideum exceeds Vegetabile in its use of traditional workshop development (62%). The majority of cases connect the development with traditional ways to develop ceramics, stone clays and stoneware. Ceramics is one of the most beloved subjects in the design field, as all techniques allow to produce small series of an object with high levels of detail and finish.

Figure 5.17
Weight of conditions for the technology source divided by kingdoms.



Kingdom Recuperavit share industrial aided technologies (37%) with workshop techniques (37%). These two trends respond to the necessity to transform materials that are difficult to manipulate with standard tools and require higher temperatures. On the other hand, some docile materials like the ones coming from recuperating food sources allow transformations with standard tools.

Kingdom Mutantis by the nature of the cases that includes, have a higher tendency to use makers related technologies (48%). The difference between self-technological development and makers is the addition to digital technologies. According to Anderson (2012), makers mix bits and atoms.

For the materials and crafts sources no graphics were plotted. This occurs mainly as in the case of the material source explained above, is a condition to allow a better evaluation and classification of the kingdom but when it comes to retrieve quantitative data, this doesn't provide additional insights. Regarding craft source the pentagon evaluation instrument already provides enough insights and no additional quantitative data could add more information to the research.

5.6. Conclusions

Chapter five presents an evaluation of the different cases collected. The qualitative and quantitative evaluation of the cases inside the five kingdoms provides valuable data to confirm hypothesis **(WH2)**. The DIY-Materials phenomenon is actually growing, and the different evaluation instruments developed to examine the cases allow a greater understanding when it is divided into kingdoms. The different characteristics of each kingdom appear visible by reading both qualitative and quantitative data. The similarities that the different cases inside a kingdom have, emerge when the single case evaluations are put one on top of the other.

The evaluation and the developed instruments for that matter were seen on the Kingdoms level because from the beginning of the research the validation sheets were connected with the kingdoms and not with the subcategories using the conditions with a pentagonal shape. The subcategories emerged afterward.

From the data extracted by the evaluation instruments, it is possible to conclude that each kingdom is starting to show a particular sensorial unity. The aesthetics perception of each kingdom differs from the others. This perception, when further evaluated, will provide more descriptive characteristics inside each kingdom, recognizable also by every single material. These characteristics and particularities are the focus of the following chapter.

The transformation of data from qualities into numerical data allowed to determine trends inside kingdoms. The study was conducted in the triangulation sessions by a small team of researchers. However, the evaluation instruments have been sharpened and now is possible to re-evaluate the cases with a broader group of researchers to observe if the trends remain similar.

Chapter Six

Second Study: Aesthetical evaluation of DIY-Materials

Humans live in a material world and are part of the material culture (Holloway, 1969; Ingold, 2012). In this world created either by nature or by humans (McDonough & Braungart, 2002), perception becomes a tool to understand and give meaning to the multiple signals and features arriving from all that surrounds us. Some scholars (Nanay, 2015) urge the consideration of aesthetics as the philosophy of perception, which means that aesthetics deals with the study of sense perception. The philosophy of perception is also about experiences and aesthetic is about ways of experiencing the world.

In the contemporary aesthetics, STEM materials play a key role, as they prescribe how things may look based on the manufacturing processes enabling their transformation (Papanek, 1971; Ashby & Johnson, 2002; Rognoli, 2005). The uniformity, precision, and repeatability usually associated with the STEM materials provide a particular aesthetics that make the contemporary industrial status of artifacts recognizable. However, despite all technological and industrial developments of the last three hundred years (Kondratiev, 1998; Alexander, 2001; Moulaert, 2009) the rebirth of the aesthetics of imperfection seems remarkable (Ostuzzi et al., 2011 a; Rognoli & Karana, 2014; Ostuzzi, 2018). In fact, the presence of imperfection is grown, generating a pleasurable balance that connects the mere essence of our humanity and naturalness.

This aesthetics of imperfection is not a new issue. It belongs to the ancient world, where defects, inhomogeneity, signs, traces, and wear and tear were considered beautiful even before industrialisation changed the paradigm (Rognoli & Karana, 2014). The valorisation of imperfection (Ostuzzi et al., 2011 a) provides more emotional bonds and emphasizes the relationship with objects just because it reflects the endless ways in which human beings interact and live with

them (Chapman, 2005). It is well known how the ancient Japanese tradition of Wabi-Sabi promoted the beauty of the imperfect things (Koren, 2002), where the beauty of the physical world reflects the irreversible flow of life (Juniper, 2003). Everything that is faded, eroded, oxidized or scratched goes beyond the beauty-ugly dichotomy and moves into the ordinary-extraordinary level (Sartwell, 2006).
This chapter focuses on the aesthetics of DIY-Materials and the perception patterns formed by the attributes and qualities of this growing phenomenon. The principal question leading this particular investigation inside the Ph.D. research is: Which are the aesthetics of a DIY-Material? What are the most important attributes and qualities defining their aesthetic?

With the use of the DIY-Material classification explained in the previous chapters, some instruments were built to interpret the aesthetic of this new class of materials. It can be the starting point to understand one of the emerging trends for the next aesthetics in design. This study builds upon the theoretical background explained in chapter three, and it was presented in 2017 in the EAD12: Design for the next conference in Rome under the name: The new aesthetics of DIY-Materials (Ayala-Garcia & Rognoli, 2017). This chapter contains extracts from the paper and is extended and enriched with some in-depth description of the evaluation instruments and parameters.

6.1. Early observations on DIY-Materials aesthetic

DIY-Materials denote an alternative to materials science development. In the DIY-Materials development, the designers, unlike scientists or engineers, are the primary drivers of the process. The designer outlines identity and meaning of the samples of materials, characterizing them from an expressive-sensorial point of view (Rognoli, 2010), and defining the patterns of the experiential qualities (Karana et al., 2015).
DIY-Materials usually derive from the transformation of unconventional sources as explained in **chapter four** (e.g., grown vegetables, animal constituents, basic minerals, recuperated waste or a modification of a standard material with any available technology). They respond to a particular purpose as described in **chapter five** (e.g., tackle a wicked problem, make a particular statement or go beyond the mass customised solutions) and they result from various inspirations.
The sources of DIY-Materials are also the key elements for establish-

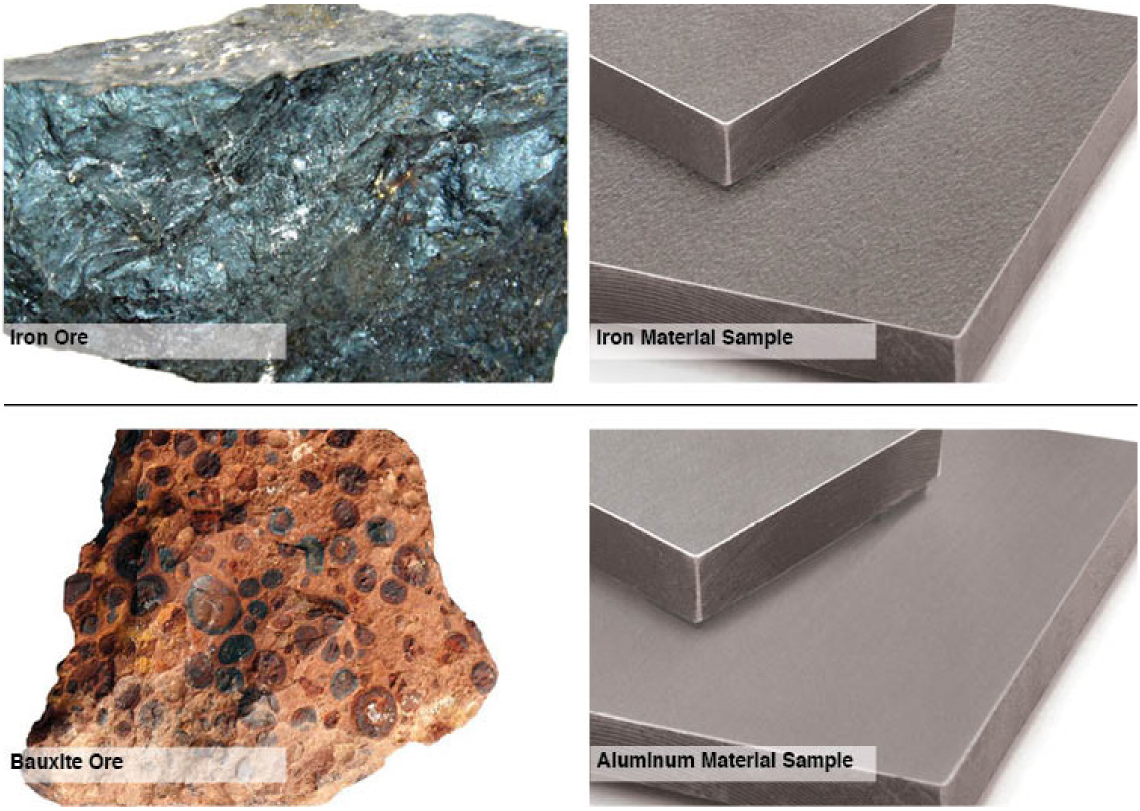


Figure 6.1
Samples of Iron and Aluminum compared with their respective sources.

ing this "new class" of materials. The kingdoms categorization takes inspiration from the first biological classification of the seventeenth century based on the work of the Swedish botanist, zoologist and physician Carolus Linnaeus, called Systema Naturae (Linnaeus, 1758) as explained in **chapter four**. Comparable to Linnaean taxonomy, the DIY-Materials kingdoms principally refer to the sources or ingredients that allow the development of a particular material. The five kingdoms are named as follows:

-*Kingdom Vegetabile* when the primary source for a DIY-Material derives from plants and fungi.
-*Kingdom Animale* refers to sources derived from animals and bacteria.
-*Kingdom Lapideum* contains all DIY-Materials, which come from minerals: stones, sand, ceramics, clay, etc.
-*Kingdom Recuperavit* covers all sources society considers as waste but with the opportunity to transform them into a valuable resource.
-*Kingdom Mutantis* includes the DIY-Materials created from different technological mixes and hybridization of industrial, interactive or smart sources.

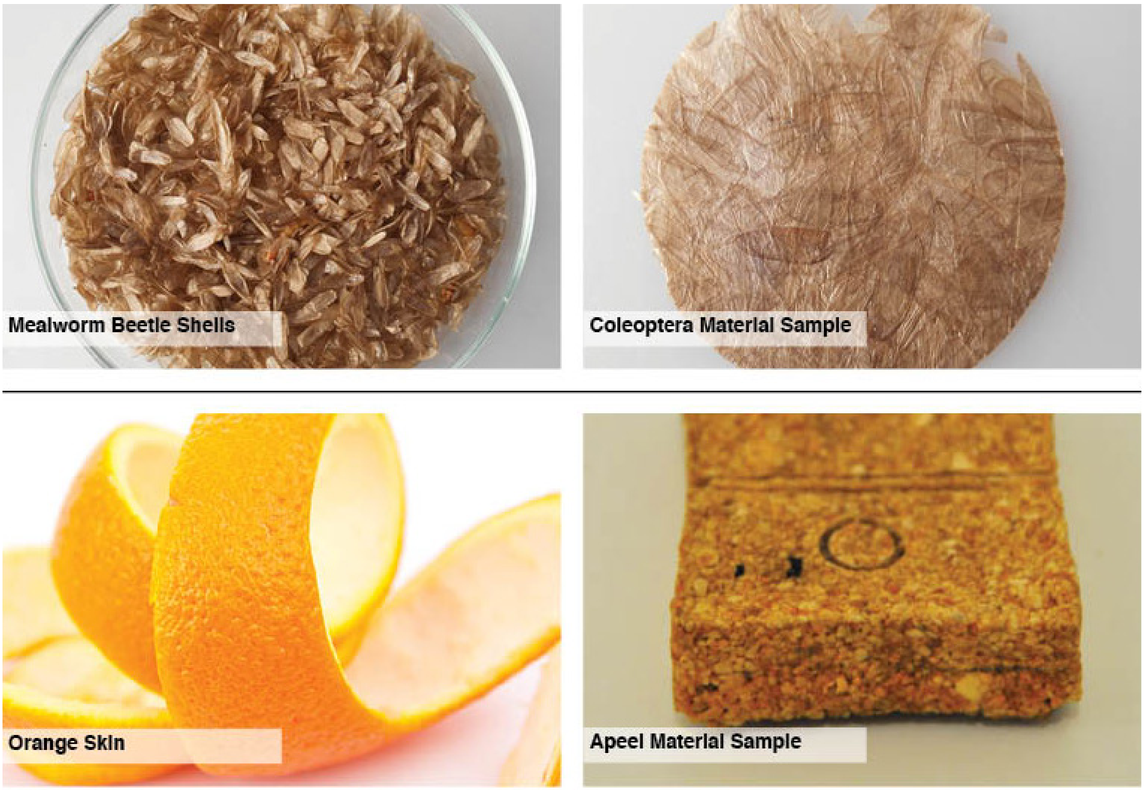
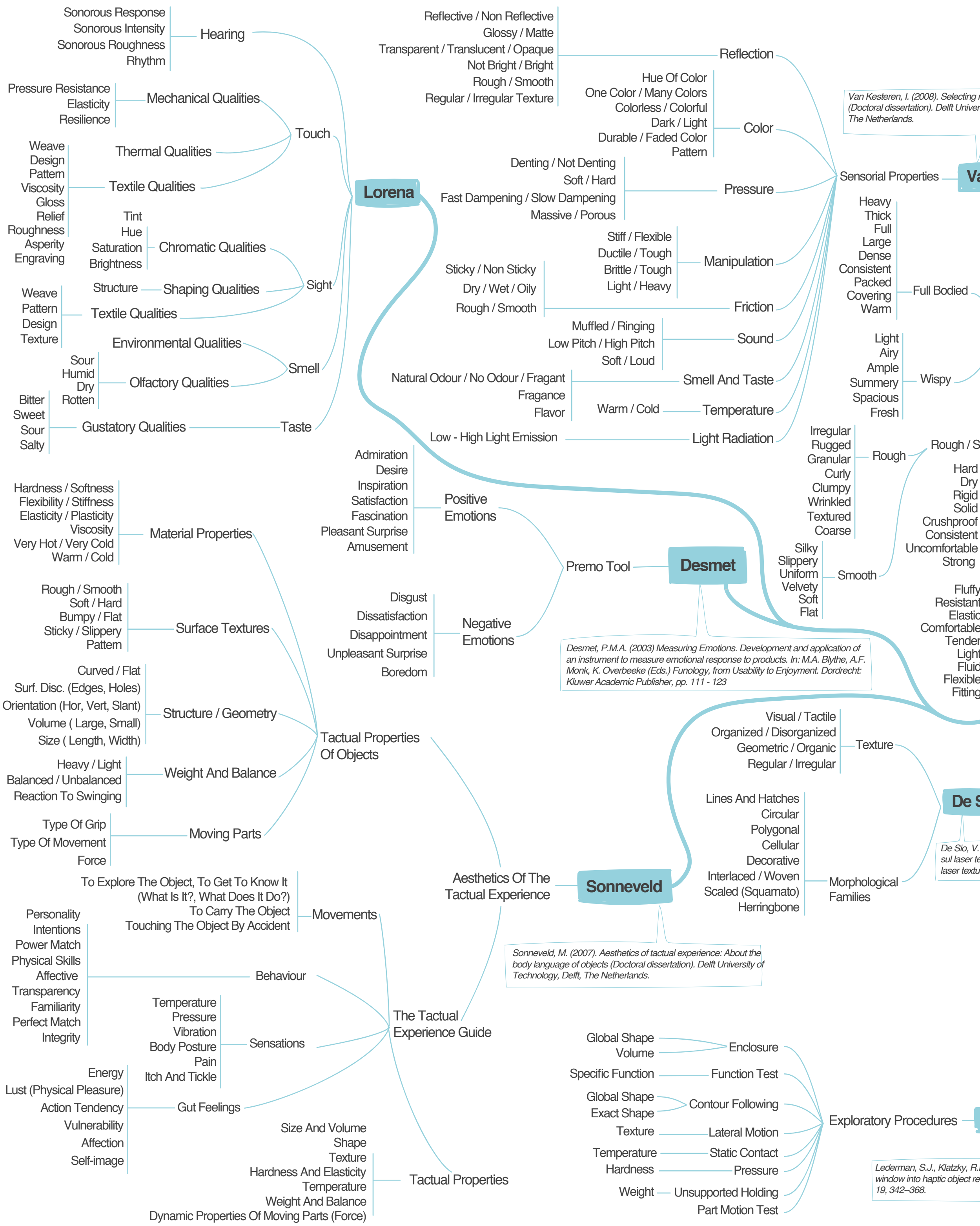


Figure 6.2
DIY-Materials made out of mealworm beetle shells and discarded orange skins.

The perfect and uniform surfaces characterizing the STEM materials, in general, provide an artificial aesthetics far from what our daily contexts usually exhibit. In fact, everyday life is broadly identified with aesthetics based on imperfection and ageing. Gillo Dorfles makes a clear statement around the topic when he states: “Imperfection, asymmetry and unfinished, even the broken the shattered and the reassembled are very useful concepts for the aesthetic enjoyment of the world around us” (Dorfles, 2005). The DIY-Materials aesthetic seems to be more consistent with the real situation of the context we live.
In addition, it is possible to investigate and find that DIY-Materials have peculiar aspects characterizing their aesthetic and affecting the user’s materials experience.
When exploring standard samples of Iron or Aluminium (Figure 6.1), it is difficult to perceive their original sources (iron and bauxite) as their principal constituents are not evident. By contrast, when holding a DIY-Materials sample such as Coleoptera by Aagje Hoekstra or Apeel by Alkesh Parmar (Figure 6.2), it is easy to recognize the origins and the compositions of both materials: mealworm beetle shells for



Sonorous Response
Sonorous Intensity
Sonorous Roughness
Rhythm
Hearing
Pressure Resistance
Elasticity
Resilience
Mechanical Qualities
Touch
Thermal Qualities
Weave
Design
Pattern
Viscosity
Gloss
Relief
Roughness
Asperity
Engraving
Textile Qualities
Tint
Hue
Saturation
Brightness
Chromatic Qualities
Structure
Shaping Qualities
Sight
Weave
Pattern
Design
Texture
Textile Qualities
Environmental Qualities
Sour
Humid
Dry
Rotten
Olfactory Qualities
Smell
Bitter
Sweet
Sour
Salty
Gustatory Qualities
Taste
Lorena
Reflective / Non Reflective
Glossy / Matte
Transparent / Translucent / Opaque
Not Bright / Bright
Rough / Smooth
Regular / Irregular Texture
Reflection
Hue Of Color
One Color / Many Colors
Colorless / Colorful
Dark / Light
Durable / Faded Color
Pattern
Color
Denting / Not Denting
Soft / Hard
Fast Dampening / Slow Dampening
Massive / Porous
Pressure
Stiff / Flexible
Ductile / Tough
Brittle / Tough
Light / Heavy
Manipulation
Sticky / Non Sticky
Dry / Wet / Oily
Rough / Smooth
Friction
Muffled / Ringing
Low Pitch / High Pitch
Soft / Loud
Sound
Natural Odour / No Odour / Fragant
Fragance
Flavor
Smell And Taste
Warm / Cold
Temperature
Low - High Light Emission
Light Radiation
Sensorial Properties
Van Kesteren, I. (2008). Selecting
(Doctoral dissertation). Delft Univer
The Netherlands.
Va
Heavy
Thick
Full
Large
Dense
Consistent
Packed
Covering
Warm
Full Bodied
Light
Airy
Ample
Summery
Spacious
Fresh
Wispy
Irregular
Rugged
Granular
Curly
Clumpy
Wrinkled
Textured
Coarse
Rough
Rough / S
Hard
Dry
Rigid
Solid
Crushproof
Consistent
Uncomfortable
Strong
Silky
Slippery
Uniform
Velvety
Soft
Flat
Smooth
Fluffy
Resistant
Elastic
Comfortable
Tender
Light
Fluid
Flexible
Fitting
Admiration
Desire
Inspiration
Satisfaction
Fascination
Pleasant Surprise
Amusement
Positive Emotions
Disgust
Dissatisfaction
Disappointment
Unpleasant Surprise
Boredom
Negative Emotions
Premo Tool
Desmet
Desmet, P.M.A. (2003) Measuring Emotions. Development and application of an instrument to measure emotional response to products. In: M.A. Blythe, A.F. Monk, K. Overbeeke (Eds.) Funology, from Usability to Enjoyment. Dordrecht: Kluwer Academic Publisher, pp. 111 - 123
Hardness / Softness
Flexibility / Stiffness
Elasticity / Plasticity
Viscosity
Very Hot / Very Cold
Warm / Cold
Material Properties
Rough / Smooth
Soft / Hard
Bumpy / Flat
Sticky / Slippery
Pattern
Surface Textures
Curved / Flat
Surf. Disc. (Edges, Holes)
Orientation (Hor, Vert, Slant)
Volume (Large, Small)
Size (Length, Width)
Structure / Geometry
Heavy / Light
Balanced / Unbalanced
Reaction To Swinging
Weight And Balance
Type Of Grip
Type Of Movement
Force
Moving Parts
Tactual Properties Of Objects
Visual / Tactile
Organized / Disorganized
Geometric / Organic
Regular / Irregular
Texture
De S
De Sio, V.
sul laser te
laser textu
Lines And Hatches
Circular
Polygonal
Cellular
Decorative
Interlaced / Woven
Scaled (Squamato)
Herringbone
Morphological Families
Aesthetics Of The Tactual Experience
Sonneveld
Sonneveld, M. (2007). Aesthetics of tactual experience: About the body language of objects (Doctoral dissertation). Delft University of Technology, Delft, The Netherlands.
To Explore The Object, To Get To Know It (What Is It?, What Does It Do?)
To Carry The Object
Touching The Object By Accident
Movements
Personality
Intentions
Power Match
Physical Skills
Affective
Transparency
Familiarity
Perfect Match
Integrity
Behaviour
Temperature
Pressure
Vibration
Body Posture
Pain
Itch And Tickle
Sensations
The Tactual Experience Guide
Energy
Lust (Physical Pleasure)
Action Tendency
Vulnerability
Affection
Self-image
Gut Feelings
Size And Volume
Shape
Texture
Hardness And Elasticity
Temperature
Weight And Balance
Dynamic Properties Of Moving Parts (Force)
Tactual Properties
Global Shape
Volume
Enclosure
Specific Function
Function Test
Global Shape
Exact Shape
Contour Following
Texture
Lateral Motion
Temperature
Static Contact
Hardness
Pressure
Weight
Unsupported Holding
Part Motion Test
Exploratory Procedures
Lederman, S.J., Klatzky, R.
window into haptic object re
19, 342–368.

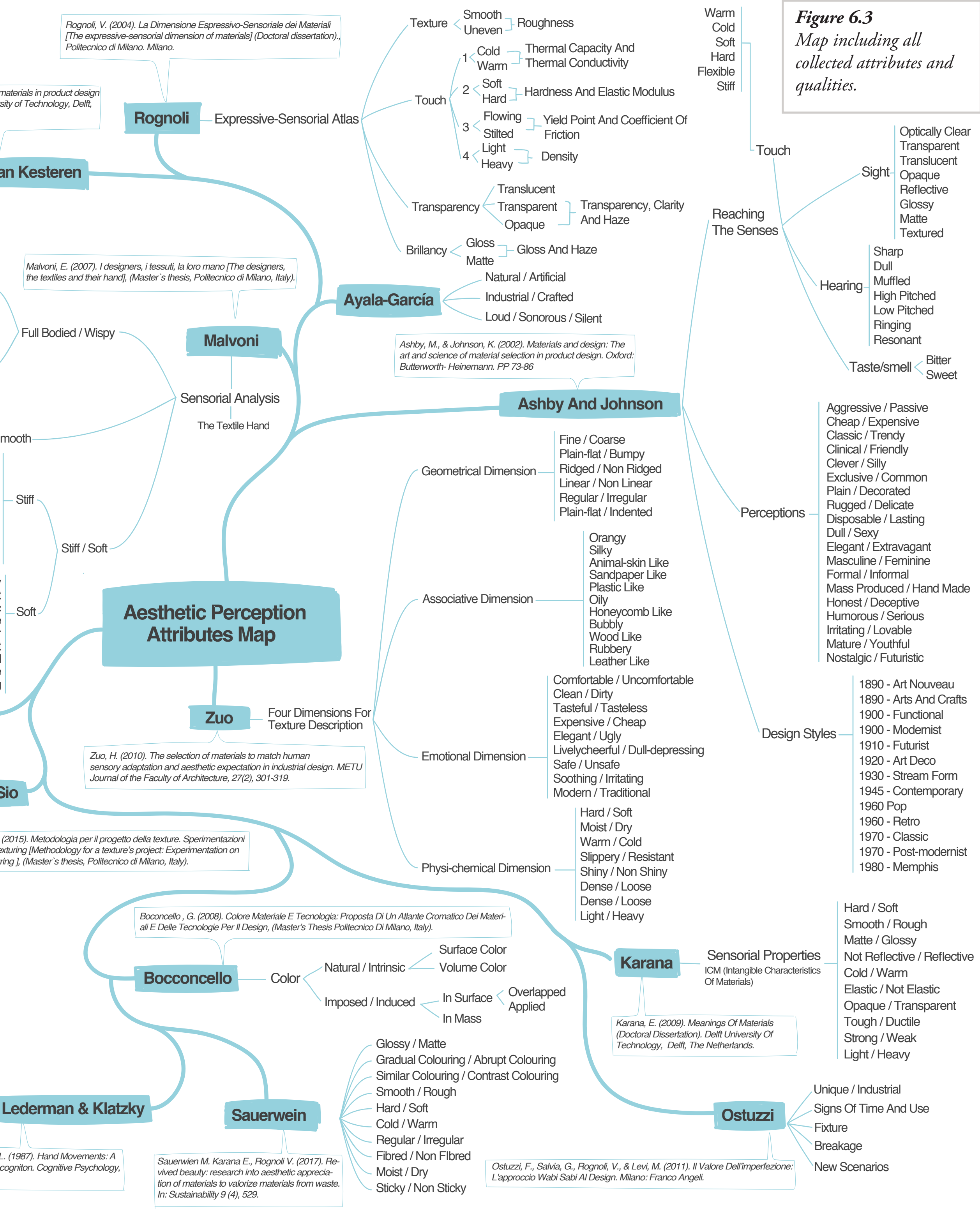


Figure 6.3
Map including all collected attributes and qualities.

the first sample and orange skin for the second.

As a result of this first step of observation, it is possible to affirm that the aesthetic of DIY-Materials is described by the evidence of their principal sources.

DIY-Materials then provide another aesthetical richness that is worth investigating. In fact, the concept of traces originated by a craftsman's hands work (Casciani, 1988; Sennett, 2008; Robbins et al., 2015), and the idea of serendipity (Walpole, 1754) become relevant topics for self-produced materials practices.

6.2. Towards an DIY-Materials aesthetic map

In a situation where perfection saturates markets, media and products, DIY-Materials emerge to create new aesthetics for an alternative future and people need appropriate instruments to understand and accept them.
Due to an evident lack of studies and literature, this second study started as an investigation into aesthetic perception by looking at the previous studies from other scholars focused on materials and their aesthetic aspect. All the sensorial attributes and qualities described by scholars in different methods and tools for the qualitative evaluation of materials were collected and organized. Then, all those attributes constructed a map (Figure 6.3). The different academic studies on aesthetics attributes of materials are: The Expressive Sensorial Atlas (2005 p.121); The Multi-Dimensional Materials Charts (Ashby & Johnson, 2002); The Meaning-Driven Materials Selection (Karana, 2009); The Color Atlas (Boconcello, 2008); Designing With Wabi-Sabi (Ostuzzi et al., 2011b); The Textile Atlas (Malvoni, 2009); The Aesthetics of Tactual Experience (Sonneveld, 2007); The Exploratory Procedures For Tactual Properties (Lederman& Klatzky, 1985); Materials and Emotion (Crippa, 2009); The Texture Atlas (De Sio, 2015); The Material Aesthetic Database (Zuo, 2010) and The Material Perception Tool (Van Kesteren, 2008).
Acknowledging that the definition of aesthetic is part a concept based on the philosophy of perception, the DIY-Materials aesthetic map can be seen as a collection of different attributes assigned to describe a sensorial/perceptive quality of materials.
In this chapter, it is possible to read the DIY-Materials aesthetics

by understanding the different attributes that all materials inside a kingdom commonly share. Each kingdom is represented by a material board using meaningful images from the included case studies. The collage of images is accompanied by the different list of attributes and qualities of the map. Together they create a recognizable aesthetic identity.

1. From The Oxford Dictionary of American Usage and Styleby Bryan Garner. Copyright 1995 by Bryan A. Garner. Published by Oxford University Press, Inc., www.oup-usa.org

6.3. Evaluation instruments

The different Kingdoms were evaluated and organized by the attributes coming from the different mapped tools. To give more coherence and avoid confusion, it was necessary to follow a grammatical rule. A chart known as the royal order of adjectives, which is a rule in the English language where an adjective modifies a noun became the right choice. When more than one adjective comes before a noun, the

Figure 6.4
Royal order of adjectives with collected attributes for materials.

The Royal Order of Adjectives for DIY-Materials Aesthetics Attributes

		Physical Description									
Determiner (number)	**Observation (opinion)**	**Size**	**Physical quality**	**Shape & Surface**	**Age**	**Color**	**Origin**	**Material**	**Type (Style)**	**Qualifier (purpose(ing))**	**Noun**
a	Loud	Full	Cold	Smooth	Disposable	Surface Color	Natural	Silky	Classic	Breakage & Fixture	Force
an	Sonorous	Large	Warm	Uneven	Lasting	Volume Color	Artificial	Plastic Like	Trendy	Breakage & Future Scenarios	Vibration
four	Silent	Ample	Soft	Flowing	Mature	Patina	Industrial	Wood Like	Futuristic	Denting	Body Posture
her	Aggressive	Spacious	Hard	Stilted	Youthful	Uneven	Crafted	Rubbery	1890 - Art Nouveau	Not Denting	Pain
his	Passive	Fitting	Light	Textured	Timeprints	Subtle	Technological	Leather Like	1890 - Arts and Crafts	Fast Dampening	Itch
our	Cheap	Length	Heavy	Plain	Useprints	Vivid	Masculine	Silky	1900 - Functional	Slow Dampening	Tickle
those	Expensive	Width	Transparent	Decorated		Cold	Feminine	Velvety	1900 - Modernist		Energy
that	Clinical	Size	Translucent	Rugged		Warm	Mass Produced		1910 - Futurist		Lust (Physical Pleasure)
several	Friendly	Massive	Opaque	Delicate		Similar	Hand Made		1920 - Art Deco		Vulnerability
some	Clever		Gloss	Smooth		Contrasting	Unique		1930 - Stream Form		Affection
	Silly		Matte	Rough		Gradual Transitions	Industrial		1945 - Contemporary		Balance
	Exclusive		Warm	Repetitive		Fast Transition			1960 Pop		Admiration
	Common		Cold	Non Repetitive		Tint			1960 - Retro		Desire
	Dull		Soft	Fine		Hue			1970 - Classic		Inspiration
	Sexy		Flexible	Coarse		Saturation			1970 - Post-Modernist		Satisfaction
	Elegant		Stiff	Plain-Flat		Brightness			1980 - Memphis		Fascination
	Extravagant		Optically Clear	Bumpy		Hue			Orangy		Pleasant Surprise
	Formal		Transparent	Ridged		Uni-color			Animal-skin Like		
	Informal		Translucent	Non Ridged		Multi-color			Sandpaper Like		
	Honest		Reflective	Linear		Colorless			Oily		
	Deceptive			Non Linear		Colorful			Honeycomb Like		

adjectives are normally in a particular order. Adjectives which describe opinions or attitudes usually come first, before more neutral, factual ones[1]. For this investigation, the adjective modifies the material perception and the way they are assembled together becomes a way to recognize attributes and characteristics from the kingdom and from the case itself (Figure 6.4). When describing a material it is important to highlight attributes using this royal order to provide a clear understanding or the qualities of a single material (e.g. Hidden beauty is an extravagant flexible natural new material from animal guts; Polyfloss is a cheerful light irregular material obtained by recycling thermoplastics). The chart helps in the description of the different materials inside the open source database (diymaterials.it). In the databases it is possible to find the particular attributes of the material and the ones that share with the kingdom that are shown in the tables below. The following tables which accompany the aesthetical boards, contain all different and similar attributes that emerged from the evaluation of the single cases. Those attributes together represent an enriched idea of what the materials inside a kingdom could elicit.

Figure 6.5
Material board for Kingdom Vegetabile.

Kingdom Vegetabile Attributes

Cheap	Matte	Irregular	Expendable	Crafted	Similar Colors	Traditional	Breakage: New Scenarios
Common	Light	Uneven Texture	Signs of Time and Use	Hand Made	Patina of Time		
Informal	Weak	Textured		Unique	Natural Color in Volume		
Honest	Natural Odor	Rugged			Subtle Color		
Unsafe	Natural	Curly			Non-Uniform Coloration		
	Warm	Organic					
	Smelly	Rough					
		Coarse					
		Freedom of Shape					

Figure 6.6
Aesthetical Attributes of Kingdom Vegetabile.

6.4. Kingdom Attributes

6.4.1. Kingdom Vegetabile

Kingdom Vegetabile includes DIY-Materials with a primary source derived from plants and fungi. While composing and then exploring the material board (Figure 6.5), some similar characteristics common to all the cases studied have emerged. One of these is the traceability of the source, which means, it is possible to see and recognize traces of the main constituents (e.g. plant leafs, fibers and wedges). Another peculiar characteristic of the aesthetic exploration of the DIY-Materials belonging to the Kingdom Vegetabile is the imperfection of the surfaces concerning the touch and sight perception.

In most cases, materials show unevenness and roughness which provide some particular feature to the material itself or to the designed object that embodies the material. As a consequence of their natural and organic sources, the short life attribute of the material is clearly visible among all samples. Traces of decay, flaws and broken edges are reminders of the fragility and delicacy of each material, even if the life cycle can be estimated in periods of years. The inherent degradability of the material is always present.
In the table of figure 6.6 it is possible to find the aesthetic attributes and qualities listed looking at the material board. These attributes came from the DIY-Materials aesthetic map and were listed by the author.

6.4.2. Kingdom Animale

DIY-Materials belonging to the Kingdom Animale refer to all material sources derived from animals and bacteria. Inside Kingdom Animale, some particular attributes are evident among the cases studied and selected to compose the material board (Figure 6.7). For instance, it

Figure 6.7
Material board for Kingdom Animale.

Figure 6.8
Aesthetical Attributes of Kingdom Animale.

Kingdom Animale Attributes

Exclusive	Warm	Organized	Colorful	Unique	Fascinating
Comfortable	Soft	Irregular	Non-Uniform Coloration	Crafted	Admirable
Tender	Light	Organic	Intrinsic Color in Volume		Affective
Expensive	Flexible	Uneven Texture	Warm Colors		Surprising
Elegant	Natural	Textured	Patina of Time		
	Elastic	Rough			
	With Plasticity	Freedom of Shape			
	Temperate	Patterns on surface			

is possible to guess a high degree of malleability and flexibility of the material samples. Such characteristics can be associated with the fact that the majority of the samples are cells, skins or tissues. Another notable attribute of this category shows that even if the surfaces are rough and uneven, they may express a high level of elegance and exclusivity.
Materials of animal origin such as skin, shells, furs and horns were used by several civilizations to represent particular status or the achievement of a specific goal. It is possible that the materials of this category still inherit such cultural perception. The samples collected in the material board, together with the attributes listed (Figure 6.8), show how asymmetry and imperfection become important characteristics of material.

6.4.3. Kingdom Lapideum

Kingdom Lapideum contains all DIY-Materials coming from minerals: stones, sand, ceramics, clay, etc. Some examples combine sources coming from other kingdoms, such as wool or cotton fabrics, but in a lower percentage compared with the main constituent.

Figure 6.9
Material board for Kingdom Lapideum.

Kingdom Lapideum Attributes

Expensive	Massive	Odorless	Structured	Lasting	Multi-Colored	Unique	Breakage: New Scenarios	Pleasantly Surprising
Exclusive		Dry	Geometric	Signs of Time	Patina of Time			Admirable
Formal		Thick	Consistent		Non-Uniform Coloration			
Serious		Dense	Packed		Color Induced in Mass			
Elegant		Solid	Uneven Texture		Contrasting Colors			
		Stiff	Irregular					
		Durable						
		Not Elastic						
		Tough						
		Strong						
		Cold						
		Hard						
		Heavy						
		Opaque						
		Brittle						
		Natural						
		Tough						
		Cold						

Figure 6.10
Aesthetical Attributes of Kingdom Lapideum.

Kingdom Lapideum, together with the previous two kingdoms, show the natural appearance of their main ingredients and sources. Although the degree of irregularities in the shape of the surfaces strongly diminishes, the samples of materials present corrosion, stains and random coloured surfaces (Figure 6.9). Minerals, stones and ceramics historically were used by craftsmen and designers to create objects exploiting the inner elegance, style and durability of the materials.

These aesthetic characteristics are also present in the collection of samples of this Kingdom (Figure 6.10). It is important to underline that in this category the use of machinery and instruments is clearly visible, even if they enable low-tech transformations. Those tools leave some traces and marks above the surfaces.

6.4.4. Kingdom Recuperavit

Kingdom Recuperavit incorporates all the cases studied coming from sources possibly considered as waste but transformed into a precious resource. They often come from plastic, metal or organic waste, some-

Figure 6.11
Material board for Kingdom Recuperavit.

Kingdom Recuperavit Attributes

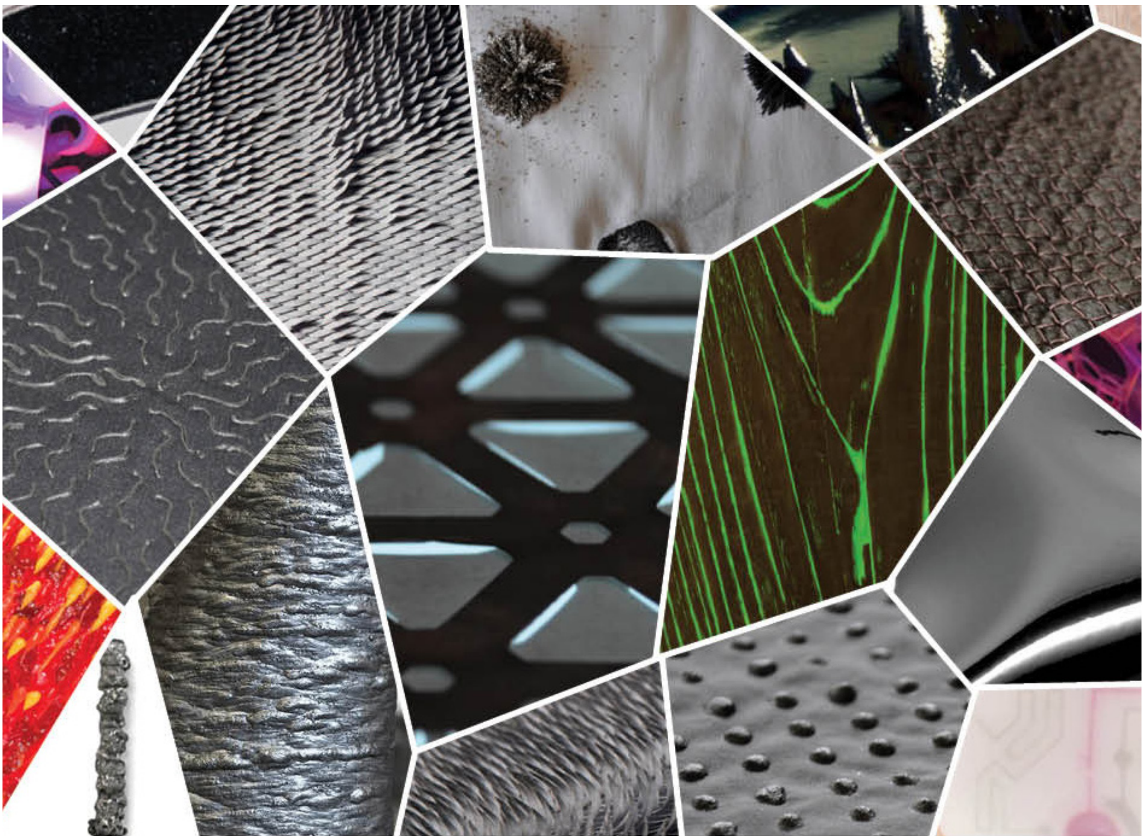
Clever	Full	Hard	Granular	Youthful	Saturated	Unique	Trendy	Breakage: New Scenarios & Fixture	Unsatisfying
Honest		Dry	Packed	Signs of Time and Use	Color Imposed in Mass	Industrial	Modern		
Ugly		Thick	Freedom of Shape		Non-Uniform Coloration				
Disgusting		Dense	Clumpy		Contrasting Colors				
Dirty		Dense	Irregular		Colorful				
Irritating			Rough		Vivid Color				
Common			Uneven Texture		Patina of Time				
Unsafe			Rugged						
Uncomfortable			Consistent						

Figure 6.12
Aesthetical Attributes of Kingdom Recuperavit.

times as side-products of industrial production.
It is the kingdom with the biggest number of cases, and it is the more complex concerning aesthetical exploration. The different upcycled sources of the material samples (industrial excess, pieces of plastic, dust and leftovers of food) are observable (Figure 6.11). These DIY-Materials have to carry with the aesthetical qualities of the previous state of their sources. For example, coffee grains maintain their original colour and texture; plastic particles exhibit their vivid colour or smooth surfaces and wood scraps show their original fibres.

Certainly, it is possible to appreciate those embodied attributes or qualities when they appear in the previous state of the constituent's material, but once they are mixed into the new samples, some people can appraise them as negative. By contrast, the fusion that appears inside some samples creates a fascinating appearance that suggests new possible scenarios of use for the new material. The contrasting aesthetical attributes for the kingdom recuperavit appear in figure 6.12.

Figure 6.13
Material board for Kingdom Mutantis.



Kingdom Mutantis Attributes							
Clever	Full Bodied	Gloss	Packed	Cold Color	Industrial	Futuristic	Desirable
Expensive		Resistant	Fine	Color Imposed in Mass	Technological	Modern	Fascinating
Aggressive		Sharp	Organized	Similar Colors	Artificial		
Serious		Balanced	Uneven Texture		Mass Produced		
Exclusive		Durable	Regular				
Safe		Strong	Geometric				
		Odorless	Consistent				
		Dense					
		Thick					
		Cold					

Figure 6.14
Aesthetical Attributes of Kingdom Mutantis.

6.4.5. Kingdom Mutantis

Kingdom Mutantis includes the DIY-Materials created from different technological mixes and hybridization of industrial, interactive or smart sources. The combinations of different material sources originate from another kingdom but evolve into something particular with the aid of any technology are also present.
During the evaluation of the cases included in the material board of Kingdom Mutantis (Figure 6.13), some challenges emerged. The convergence of technological, industrial and smart sources makes the aesthetical language more complex. However, after evaluating the cases inside this kingdom, some similarities appear. All materials present some cleverness, which it means showing in their body and surface, the capability to respond to particular stimuli or invite a specific kind of interactions.

Modernity, artificiality and futuristic look become attributes that prevail in the evaluation of the samples. The high reflective surfaces, luminescent parts or translucent components make the connection with High-Tech or smart materials developed by science evident.
This Kingdom differs from the previous four because the existence of these materials depends on specific technologies. In other words, to self-produce any of these materials, industrial aid and support of the

latest technologies available become necessary. Despite the fact that this kingdom can be perceived very close to the high industrial materials of the science and engineering domain, the DIY approach provides the aesthetical value of imperfection that allows those samples to belong to the DIY-Materials class (Figure 6.14).

6.5. Discussion

This study illustrates the possible pathway for a DIY-Materials aesthetic evaluation. Material boards for each kingdom were composed and assessed. For the assessment, a collection of attributes and qualities were taken from all the different theories and studies around the aesthetical and sensorial aspect for materials in the field of design.
The aim of this chapter is to demonstrate the aesthetic potential of DIY-Materials, pointing out the differences between the aesthetic dimension of STEM material which is mostly affected by the technologies that process the material, and the aesthetic of DIY-Material which carries and expresses the values of the original sources and the designer`s purpose. It is established that people experience and perceive materials in different forms and the application of a material creates a particular material experience pattern (Karana et al., 2015).
There is a chance in the following decades that the DIY-Materials will work as surrogates, similar to what happened to STEM materials development in the past, to replace other materials used for different applications (Rognoli, 2004). Accordingly, it is important to highlight the attributes of these emerging trends in materials for design.
Thanks to the current classification of DIY-Materials kingdoms, it was possible to highlight the aesthetic attributes and qualities for each kingdom. By doing so, strategies emerged to suggest to the designers how to develop their materials, foreseeing the aesthetic experience they could obtain.

6.6. Conclusion

This exploratory study aimed to explain in-progress investigation for the aesthetics of DIY-Materials. As is demonstrated, the self-production of materials is a growing phenomenon and probably will become a standard practice in the future. The different studies on aesthetic attributes and qualities of materials developed by different scholars were crucial to evaluate the emerging class of materials, known as DIY-Materials. The reasons for this research rely on the necessity to create a proper understanding of these materials which present as an alternative to STEM materials. Such alternative can create balance in a material world that is currently submerged by an aesthetic of perfection. Homogeneity and uniformity, precision and repeatability are dominating the materials arena, thanks to the current industrial state of our society. This chapter refers to how the ancient Japanese tradition of Wabi-Sabi exalts the beauty of the imperfect things. The evaluation of the different materials with established tools for qualitative attributes made by different scholars provided a delightful source to understand the common attributes inside each kingdom. By applying standard language tools to organize adjectives together with a visual interpretation of each material, it was possible to find common trends and characteristic attributes of each kingdom. This chapter provides a visual explanation of how those values can be tracked and identified in the each of the DIY-Materials and their Kingdoms. The different materials evaluated with this tool appeared described in (www.diymaterials.it) highlighting those attributes. After an extensive evaluation of the different materials inside each kingdom, it was possible to create a general picture that describes the entire family by collecting and listing similar attributes.

Chapter Seven

Third study: DIY-Materials development level one

In the previous three chapters, the aim was to present the classification of the DIY-Materials into kingdoms. By analysing a collection of case studies systematically, it was possible to divide them into five main categories and some subcategories based on the common elements encountered. In addition, the different variables or conditions to develop a self-made material were arranged into five groups, creating instruments to evaluate the different cases. This evaluation allowed an understanding of the similarities between cases and it became crucial to tune up the kingdoms classification theory. Afterwards, chapter six presented a study of the different aesthetic languages that emerge from each kingdom, when analysing them with the various tools developed by different scholars in the materials for design domain through an aesthetical map of qualitative characteristics. This chapter will concentrate on the development of a study where different hypotheses arriving from the first studies were tested and tuned. The study was specially designed to test and validate tests hypotheses **(TH1), (TH2) and (TH3)**. In this study, the goal was to understand if it is possible for a designer under a controlled setting and specific guidance to develop a DIY-Material sample. Furthermore, the study's objective is to understand if this process is replicable and whether the results can be considered similar.

7.1. Developing a course as a study in the doctoral research

The first exploratory studies presented in chapters four to six highlighted how the physical approach to materials is fundamental to this phenomenon described as DIY-Materials. It sounds obvious at the beginning, but it is important to underline how in the STEM sciences, where the common materials development occurs, most often the materials appear by chemical reactions inside controlled laboratories or heavy machinery with extreme ranges of temperature. Many materials created by STEM sciences appear without the direct intervention of human hands. it is crucial to understand how the intrinsic knowledge of crafts that many designers possess is critical for this research as it changes the perspective completely and is focused on another aspect separate from what was evident from the phenomenon before. **Chapter three** explains how one of the leading causes which allow designers to embark on a material development has to do with the democratization of technology and the open source access to information. However, without a disposition to craft, all these new available tools remain untouched, as it happens with many designers who focus more on intangible projects. This insight allowed for the formulation of another **research question (RQ2)** which states *Who can generate a DIY-Material?* This question opens up new possibilities to explore for theory building and better connect the **macro areas of research**. The study was set in the form of an elective course, inviting participants to develop a material.

7.1.1. Didactic Background

As mentioned above, the study was developed in the form of a course to test and validate the previous hypotheses. It did not start from scratch. Two previous educational experiences blended to set up the course and provided new tools to test. The selected academic experiences were chosen based on syllabus similarities as designers inside those courses were allowed to experiment with materials. The first one was called Concept Design Studio taught at Politecnico di Milano in Italy and the second one was called Design, Materials and Processes taught at Los Andes University in Colombia.

Concept Design Studio Course

The Concept Design Studio course was a curricula course for the MSc. Students of the school of design at Politecnico di Milano created to teach how to experiment with materials following the Materials Experience background[1] and the Materials Driven Design (MDD) method[2].

The primary objective of this course was to highlight the three possible strategies to consider when designing with a material: Imperfection, Dynamism, and Self-Production. A series of lectures, cases studies, and practical work allows students to understand each one

1. See Karana, E., Pedgley, O., Rognoli, V., (2014). Materials Experience: Fundamentals of Materials and Design. Elsevier.

2. See Karana, E., Barati, B., Rognoli, V., & Zeeuw van der Laan, A (2015). Material driven design (MDD: A method to design for material experiences. International Journal of Design, 9(2), 35-54.

of the strategies and decide possible paths for the second part. In the second part of the course, students were invited to produce some material samples by experimenting with ingredients, such as waste, food or plants, and gain inspiration from low tech processes and techniques coming from other disciplines, such as culinary arts and chemistry guided with the MDD method (Rognoli, Ayala-Garcia & Parisi, 2016) (Figure 7.1).

Figure 7.1
Concept design studio course examples.

Design, Materials and Processes Course

The Design, Materials and Processes course was created to teach students advanced knowledge about materials and industrial processes from a design perspective. It was an elective class for the fourth-year undergraduate design program open to students from different backgrounds.

The primary objective of this course was to develop an understanding of material properties and sensorial qualities together with available manufacturing processes. With a theoretical and experimental approach, students comprehend all the different possibilities that the industry provides to transform matter. A workshop developed together with a professional Chef, showed almost all industrial processes replicated with cooking techniques (Figure 7.2). With a hands-on approach, the students can understand the principles of manufacturing, producing objects made out of caramel, chocolate, and other edible ingredients (Ayala-Garcia, 2015).

Figure 7.2
Design, materials and processes course examples.

The second half of the course concentrates on the materials knowledge. In-depth understanding of the material families, their physical properties, and sensorial qualities are the learning objectives of this second part. At the end of the course, students submit a material sample using a self-produced approach (Ayala-Garcia, 2014).

7.1.2. Methodological Background

The study expected as output a series of deliveries that could provide data for the validation of test hypothesis **TH1** and **TH2.** Three strategies were selected to ensure the study produces similar results from each team of participants avoiding random outputs difficult to analyse. The selected strategies are Creative Toolkits, Prototyping and Storytelling and are explained in **chapter two**.

7.2. Designing Materials Experiences course first and second edition

The study aimed to encourage participants to think about the possibilities of design starting from the material and to enrich their knowledge and competences with the emerging materials experiences theories. The participants were able to have hands-on experience with materials, testing themselves with proposed exercises and were guided through the process of tinkering with the materials. The study was initially set to one edition. However, to increase the number of samples produced and to gather more quantity of data, a second edition was set. Both editions presented the same structure, course setting, theoretical stimuli, design process, and deliverables. Some adjustments between the first edition and the second edition were made, based on the analysis of the satisfaction reviews submitted by the participants of the first edition. For this dissertation, both editions are presented combined, and the different deliverables and results blended for better readability.

7.2.1. Course setting

Study three was conducted within the first year of the Master of Science of the school of design at Politecnico di Milano during the academic year 2016/2017 and 2017/2018. The setting was a classroom with close access to the laboratories and model workshops. Home experimentation was allowed as well as the participants' disclosure of safety procedures.

The number of participants was initially set to thirty. It was a fair number to perform a test, as ten groups of three people could be enough to develop at least two materials on each kingdom. A total of ninety-seven participants from thirty-two nations enrolled in the first edition of the study and eighty-one participants from twenty-nine nations enrolled in the second edition of the study producing a total of forty-six DIY-Materials. Participants came from the Master's courses in *Product Design for Innovation, Interior and Spatial Design, Design for the Fashion System, Product Service System Design, Communication Design, and Design & Engineering*. The academic level of the participants responds to one of the main findings of the previous exploratory study of chapter five in which the knowledge of crafts is a prerequisite for the development of a DIY-material.

Thanks to the diversity of backgrounds as well as the large cultural diversity present, a particular emphasis was put to enhance multidisciplinary and cultural cross-pollination. (Worth noting that in the two previous educational experiences which provided the theoretical and didactical background, the participants were predominantly from Italy and China for the Concept Design Studio Course and from Colombia for the Design, Materials and Processes Course).

The study had a duration of thirteen weeks in both editions. As the aim was not connected to improve educational methods, but on using an academic environment to test possibilities for the development of a material under defined conditions, the focus remained strictly on the material experimentation.

7.2.2 Theoretical Stimuli

During the study, experimentation and exploratory process of tinkering were promoted with theoretical stimuli. The different topics of the theoretical stimuli and the academic background were taught intentionally in a specific order to encourage designers to get in touch with matter.
Starting with the DIY-Materials Framework (Self-Production and Kingdoms Categorization) the participants were divided into teams choosing a specific kingdom to enable research actions from the very beginning. Each following theoretical stimuli was set to open a layer of inspiration and knowledge. The theoretical stimuli occurred as follows:

1. The DIY-Materials and the Kingdoms.
2. Materials Dynamism.
3. The Value of Imperfection.
4. The Materials Experience.
5. Material Driven Design.
6. Material Tinkering.
7. Material Activism.

1. The DIY-Materials and the Kingdoms

Do-It-Yourself as explained in **chapter three**, is understood as a personal materials experience (individual or collective). The development of a material by a designer features a direct integration between the creation and the production phases with high levels of autonomy compared to traditional industrial processes. The fact that informal producers substantially create DIY-Materials, makes it possible to qualify them as non-STEM materials.

Kingdoms, as noted in **chapter four**, help to place the personal research experiences into common ground, as a selected source starts to share common attributes that could be recognizable throughout the kingdom.

2. Materials Dynamism

DIY-Materials could change over time. Many materials inside this domain grow, change color, bend, and brake. Time becomes crucial as it determines the behavior of the material through its life cycle. While STEM materials tend to be immortal, perfect and durable avoiding fracture and failure, in the DIY-Materials domain the signs of time give a different dimension to each project (Figure 7.3). The matter should not be seen as a commodity, an inert substance that gains value and life when transforming into something. On the contrary, it must be considered equal to creatures, gifted with a dynamic life independent from the objects it embeds (Morozzi, 2009).

3. The value of Imperfection

Valorizing imperfection as design strategy is a crucial element to understand how auto-production of materials in its pure nature can provide a unique language in the different products that can come from them. Different from what industry through STEM produces typically, DIY-Materials can stimulate different experiences by the defects and imperfections perceived in their mass or surface (Figure 7.4).

The four strategies to valorize imperfection
Are a series of strategies developed to enhance the bonds that emerge with the user (Van Hinte, 1997), the relationship of materials and surfaces with defects and imperfections (Chapman, 2005). These strategies make users' experience richer and more enduring. Developed as a strategy to identify the elements which could valorize imperfection in industrial products (Ostuzzi, Salvia & Rognoli, 2011b), the tool provides four groups or four potential design approaches for the elongation of artefacts life-span, depending from the life-cycle step involved (production, usage, end of life). This strategy became vital during the first steps of the experimentation, as it helped to relieve the number of stress participants feel when things do not come as expected. It is a typical pattern in this type of experimentation and development process, but it is crucial to avoid participants to give up the project, and to show different strategies to consider when a material sample is going in another direction.

The four strategies are as follows.

-*Standard Unique:* manufacturing defects and differentiation seen as a possible value. In other words, if one is thinking about the material as part of a scalable production, awareness that any defect can become a feature to highlight.
-*Time and use signs:* the material and the products are dynamic elements, as explained above.
-*Breakage followed by fixing:* the sustainable emotional aspects of products' mending. DIY-Materials can break very quickly during the first phases of experimentation. Instead of adjusting the recipe or starting over, one can repair the sample creatively and obtain unexpected results.
-*Breakage followed by a new function:* the damage opens new functional scenarios.

4. The Materials experience
Defined as the experiences that people have with, and through, the materials of a product (Karana, Pedgley & Rognoli, 2014), it is the starting point for the whole understanding on what it means to self-produce materials. Materials are hardly ever selected only for their technical properties. When people describe materials, they mostly talk about how it performs. People also suggest how it looks and feels

Figure 7.3
Material Dynamism.

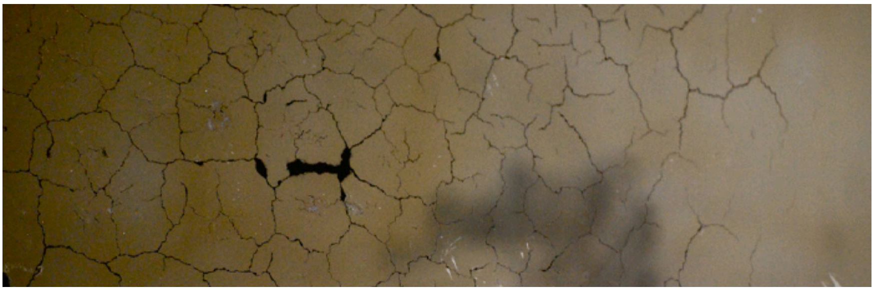


Figure 7.4
The value of imperfection.

Figure 7.5
Materials experience.

Figure 7.6
Material driven design.

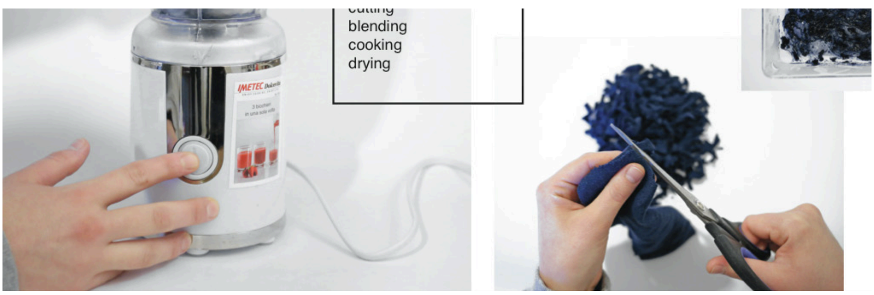


Figure 7.7
Materials tinkering.

(sensorial experience), what it expresses or the associations it recalls (meaning experience) and even how it makes them feel (emotional experience). Together these aspects make up the material experience (Karana, 2009)(Figure 7.5).

5. Material driven design

The strategy of including the material in the learning process is rooted in the Bauhaus. Johannes Itten, through the theory of contrast (Itten, 1975) explored sensorial distinctions relevant to materials. Smooth vs. rough, soft vs. hard and light vs. heavy, by showing the essential characteristics of different matter. These contrasts had to be felt and not seen. In the same fashion, Lazlò Moholy-Nagy studied the tactile experiences of materials migrating away from the “school of seeing” emphasizing the sense of touch (Wick, 2000). In the study, the focus was mainly on the first and second steps of the material driven design method (Karana, Barati, Rognoli & Van der Laan, 2015) (Figure 7.6). The first step provides essential guidelines on how to understand the material. The iterative process of understanding the material making processes, the taxonomy, characterization of experiential and technical qualities and properties and some benchmarking, helped the participants to develop a close relationship with the material they selected for development.

The second step, which served as a strategy in the latter part of the study where the materials achieve some mature level of development, helps the participants to imagine possibilities for the material in the future. The participants weren’t pushed towards the third and fourth steps of the methods, as the previous academic experiences showed that the time to achieve proper concepts for materials application should be at least equal to the one devoted to the material development. As the study took much of its time in the development process, forcing the material towards an application will only erase all achievements. Participants were advised to take the material further on their own either as a future project or by integrating it into their MSc. Thesis project[3].

3. At Politecnico di Milano Design Department it is possible to select a topic for further development choosing from the different subjects sudied during the master’s course.

6. Material tinkering

Material tinkering is a design practice characterized by specific procedures, supportive activities, and goals. Material tinkering aims to extract data, understand material properties, understand constraints and recognize its potentialities (Parisi, Rognoli & Sonneveld, 2017).

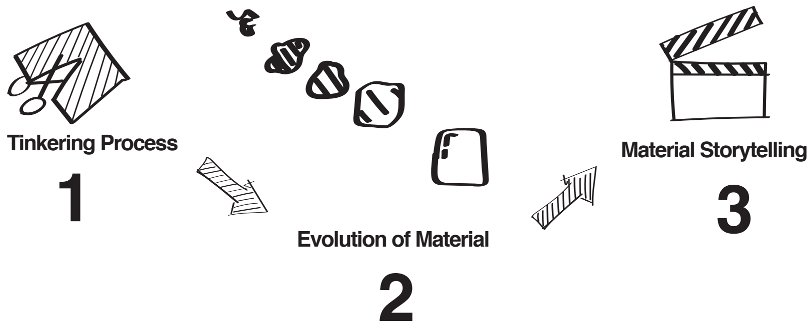
As a strategy helps participants to gain knowledge about the material and to develop procedural knowledge through experiential learning (Smith, 2001, 2010). Tinkering is a term borrowed from human-computer interaction (HCI) and points to hack[4] and manipulate materials in a naïve, playful and creative way (Cermak-Sassenrath & Møllenbach, 2014; Sundström & Höök, 2010; Buxton, 2007). Participants were allowed to have several tinkering phases throughout the study. Doing so without a project in mind, the designer uses exploratory research to push the material further. The result of the tinkering phases may look incomplete, and without a defined shape or structure. However, the different samples of material attempts reveal unique elements and achievements that can unlock a next step in the development process (Figure 7.7).

4. See chapter four 4.4.5

7. Material Activism
The concept of activism was introduced as a provocative topic to start a vigorous protest against this closed system of materials development, which as explained in chapter three tends to exclude designers based on a lack of knowledge on one hand and a dependence on the network to select the materials for a project on the other. The term materials activism was first coined by Miriam Ribul (2014) as an expression to identify a low-tech approach that would democratize the production and development of materials. In her open source publication, the author invites others through a collection of recipes for in-house material experimentation, to understand how it is possible to develop alternative models to replace traditional industrial ones, also creating new aesthetics and innovating through new materials languages. What comes into evidence is that the approach shows the emergence of another way to see materials and processes. This is an alternative and parallel view that carries within a new dimension of the relationship between designers, technology processes, and materials.

7.2.3. Design Process
Like any other design process, the development of a material followed stages of planning development and production (Cuffaro, 2006). The participants began by identifying opportunities, defined the project by doing research, conceptualize and refine the material and prepare for launching or presenting the idea. Different from product development, the DIY-Materials project concentrate in three stages: tinkering, evolution, and storytelling (Figure 7.8).

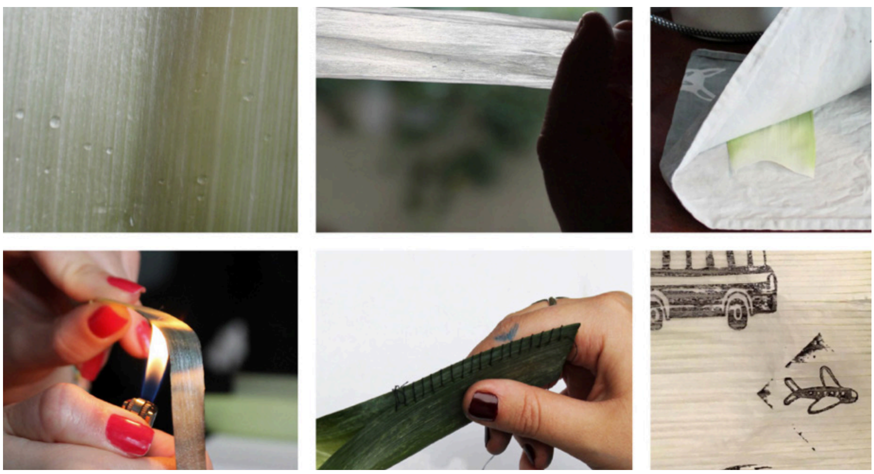
Figure 7.8
Scheme of the three steps of the study.



As the material does not will end proposing a defined application, there was no need to follow precise standard product design guidelines. Still, having a methodological structure supported by the theoretical stimuli will assure the exercise will not be a meaningless experiment but a proper design task.

Stage One (1) Tinkering process: From the selection of the kingdom to the realization of the first set of samples without filter or selection of a specific direction.
Participants were guided through the tinkering process being stimu-

Figure 7.9
Materials tinkering stage.



lated with different material samples, analysing specific case studies from a particular kingdom, providing experiential characterization tools, and analysing the low-resolution prototypes of materials samples that each week evolve and mature (Figure 7.9).
This act of following-up each team advancement revealed to be of great importance as it helps the designers to see the unseen. In this initial part, the material samples do not look right and depending on

Figure 7.10
Evolution of materials stage.

the selected source for experimentation they could not even stay as a whole. To show each team the different hidden achievements of each tinkering and experimentation phase was crucial in this part.

Stage Two (2) Evolution of material: Once the materials samples achieve some mature level of development, participants were guided to imagine possibilities for the material in the future. This step is key, as is in this envisioning process where the relationship between the designer and its material reach the top. The designers are well aware of the capabilities of the material, and the material speaks to them. This dialogue between both material and designer is vital and will guide the storytelling of the whole process (Figure 7.10).

Stage Three (3) Material Storytelling: With a collection of sam-

Figure 7.11
Material storytelling stage.

ples, images, diaries, user studies, benchmarks and different material gathered during the whole process the participants develop a story to tell about the conception of the material. While speaking about the experimentation process is crucial, it is also essential to show the different motivations, inspirations and technologies (Figure 7.11) (see also chapter five 5.1).

These stages did not occur at the same time in the study. Each team

Figure 7.12
Material datasheet provided to participants for compilation with all relevant information about the developed material.

ReFruit

Ya Xiao, Lilach Pomerantz, Elena Sophia Di Giacinto

Vegetabile

Material Properties

A strong flexible material with a different level of roughness on each side. Colorful patterns are made by using fruits with contrasting colours.

- Hard — Soft
- Smooth — Rough
- Matte — Glossy
- Not Reflective — Reflective
- Cold — Warm
- Not Elastic — Elastic
- Opaque — Translucent
- Unflexible — Flexible
- Strong — Weak
- Light — Heavy
- Unsticky — Sticky
- Odorless — Smelly

Basic Ingredients

apple, blackberries, raspberries and lemon juice

Description

The material is sustainable thanks to the fact that it gives the fruit a second life after it has gone bad or rotten. The new material is in itself ecological because it doesn't contain any chemicals, it is completely organic and for this reason it's biodegradable.

Contact

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"Restart the cycle"

Key steps

The fruit is cooked on low temperature with water and brought to the boil.

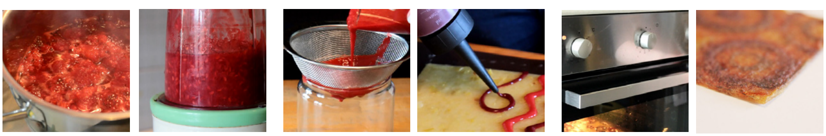
The fruits are blended into a smooth purée mixture and it's added lemon juice.

The mixture is purified from seeds with a strainer.

Mixture is spreaded on a silicone sheet and patterns are drawn with a squeeze bottle.

The material is dried in the oven at 60° for 6 to 8 hours.

The final outcome is taken out of the oven and cooled down in ambient temperature.



of participants spends different weeks in each part, and each material depending on the source and complexity of the development required two or more stages of tinkering iterations or evolution stages.

7.2.4. Deliverables

To better address the research purposes of this study, a series of deliverables were requested related to the stages of the design process and divided in **(A)** DIY-Material samples, **(B)** DIY-Material datasheet (Figure 7.12. see also Figure 5.9 in chapter five), **(C)** DIY-Materials diary and **(D)** a DIY-Materials video and **(E)** voluntary satisfaction questionnaires (Figure 7.13).
The deliveries aimed to organize the obtained data into different elements to compare the materials studied in the exploratory phases with the ones produced in the test phases and to draw conclusions. All physical samples, as well as the different media produced by each team of participants, are used to gather data for this research. On a weekly basis, each team was requested to present advancements of each stage. For **stage one (1)** the average duration was six weeks. However as

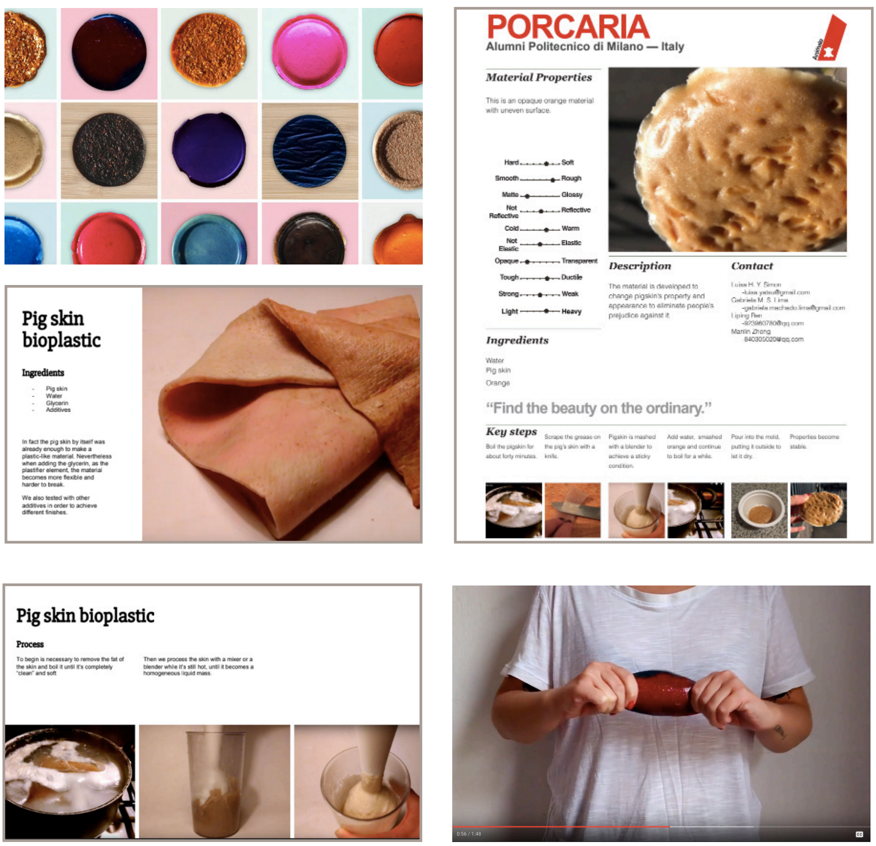


Figure 7.13
Deliverables requested to each team of participants.
(a) DIY-Material samples.
(b) DIY-Materials datasheet.
(c) DIY-Materials diary.
(d) DIY-Materials video.

explained above, if some teams were having trouble or needed extra time to explore alternatives they were granted more time as long as they were able to show advancements. For **stage two (2)** the average duration was five weeks or less if the team used extra time during the tinkering process. For **stage three (3)** the duration was set to two weeks.

It is worth noting that when talking about workload in weeks, the participant was not entirely devoted to the study. As the study was proposed as an elective course, the total weight was distributed into four hours of classroom work and eight hours of home/workshop work per week.

7.2.5. Results

The different materials produced during this study were classified inside the kingdoms as well. The results of each team were organized according to deliverables (a – d) from figure 7.13. A short description of each material appears in Appendix 02 and are accessible in the

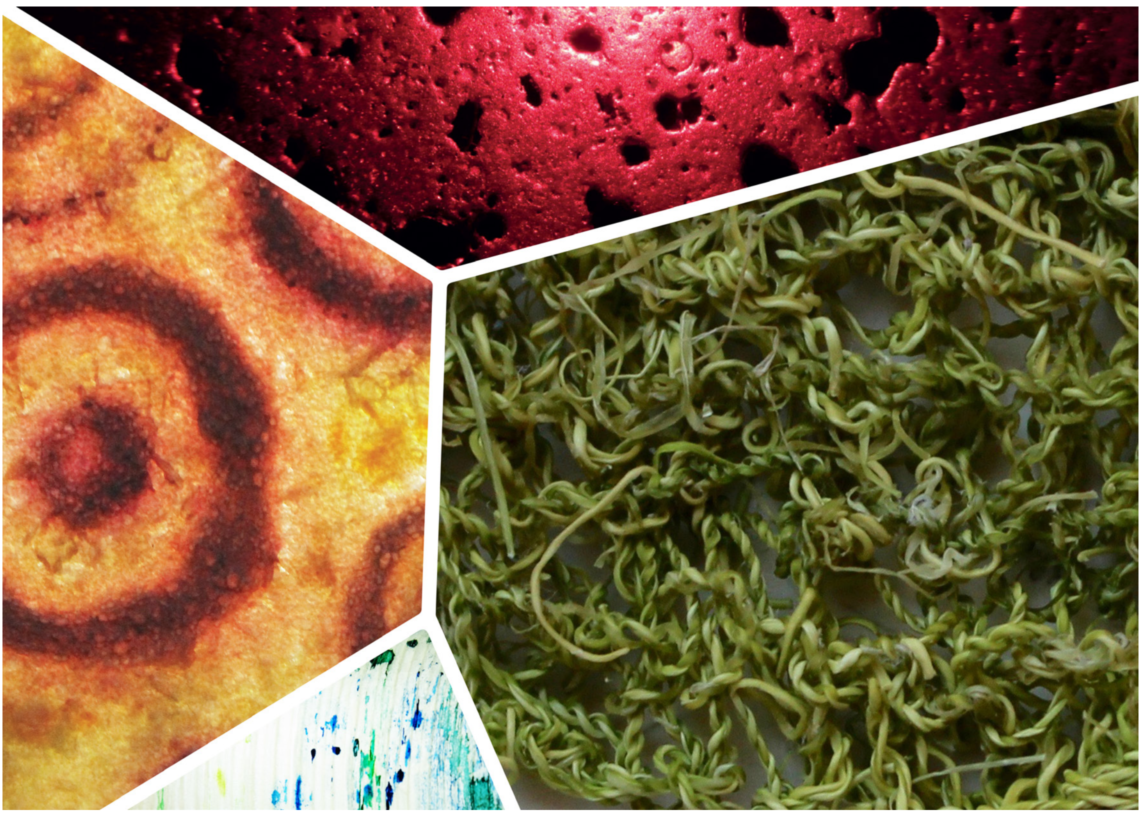


Figure 7.14
Farmed Materials Board.
From top, clockwise:
(a) Flexbeet.
(b) GreeNet.
(c) Leek paper.
(d) Refruit.

Figure 7.15
Materials that Grow Board.
From left, counter clockwise:
(a-b) Scent of Herbs.
(c) EC Grass.

DIY-Materials database (see chapter nine 9.1.2.)

Fourteen samples were classified under kingdom Vegetabile, working with vegetal sources such as leek, celery leaves or grass (Figures 7.14 and 7.15). Going back to the different subcategories inside the kingdom vegetabile explained in chapter three, we can group the results from the course regarding this kingdom into:

- Farmed Materials (8 samples).
- Wild Findings (1 sample).
- Materials That Grow (2 samples).
- Cover Skins, Peels and Natural Packages (2 samples).

Kingdom Animale obtained five material samples (Figure 7.16). As mentioned in chapter four, it is more challenging to deal with the organic matter of this kingdom. Not everybody is ready to address this type of sources, however, the ones who accept the challenge most of the time achieve incredible results. The five samples produced during the course are classified into:

Figure 7.16
Animal Remains Board.
From right, clockwise:
(a) Sea Snow.
(b-c) Porcaria.

- Animal remains (2 samples).
- Animal production (3 samples).

For Kingdom Lapideum participants developed a total of seven samples (Figure 7.17). One team didn't submit the final samples as they encounter different troubles and were not able to solve. The name was included for the overall statistical data as they were part of the whole study, but the project will not count as a result. The materials produced under this kingdom are classified into:

- Low crafted ceramics (3 samples).
- The other minerals (4 samples)

Equal to what was visible in the case studies, Recuperavit It is at the moment the most significant Kingdom by the number of projects (Figure 7.18). Inside this category, it is evident also during the course, the designer`s intention towards a more conscious and sustainable future. In the two editions, a total of eighteen samples were classified into:

- Recuperating food sources (6 samples).
- Recuperating natural sources (1 sample).
- Recuperating industrial sources (5 samples).
- Recuperating common waste (6 samples).

Kingdom Mutantis is still the most challenging kingdom. Only three projects were considered part of this kingdom during the course development. As will be discussed later, the different technological barriers that this kingdom possesses, frighten the various teams to develop a material with its sources.

-Material mutations (3 samples).

Regarding the design process, several results were significant as part of the study. Keeping track of the different achievements in the three stages of the development, provide insights for the DIY-Materials theory as well as a validation of the different posed hypothesis. For each stage the results are as follows:

Figure 7.17
The other minerals board.
From right, clockwise:
(a) Melach.
(b) Makeup Saver.
(c) Salt Sheets.
(d) Nabatea.

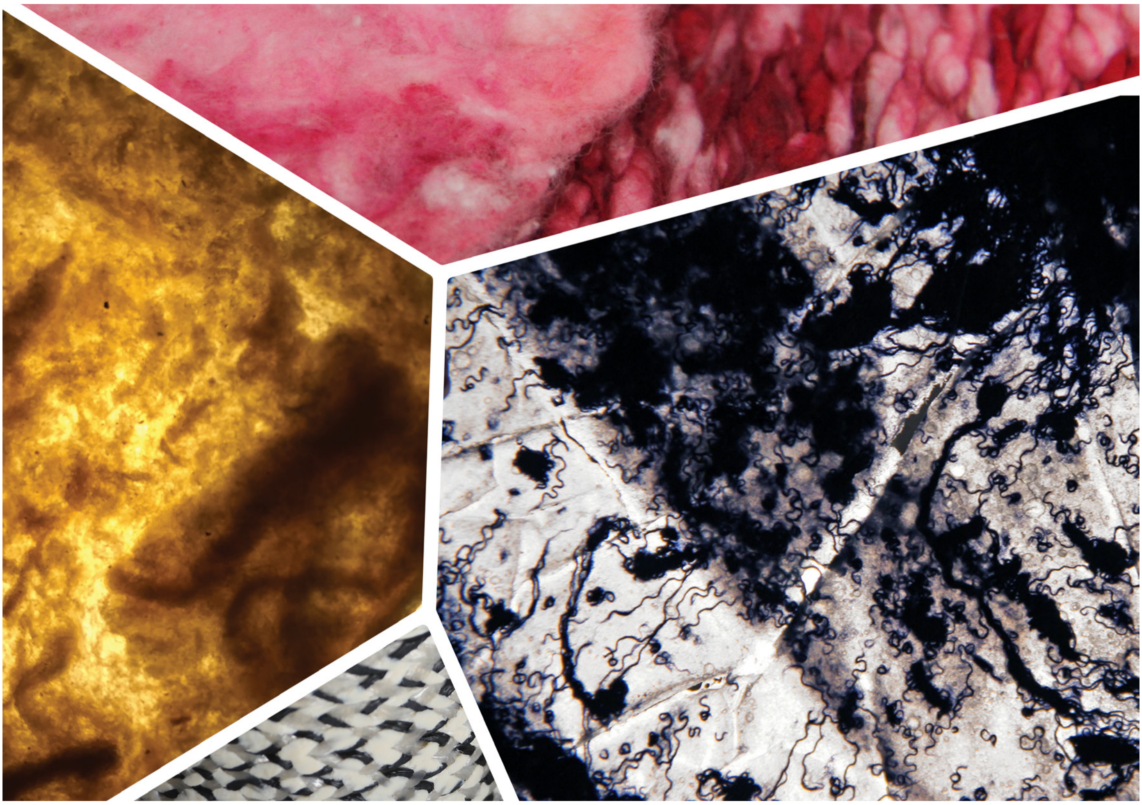


Figure 7.18
Kingdom Recuperavit Board.
From right, clockwise:
(a) Marbile.
(b) Cordeplastica.
(c) Butts Bunny.
(d) Funco.

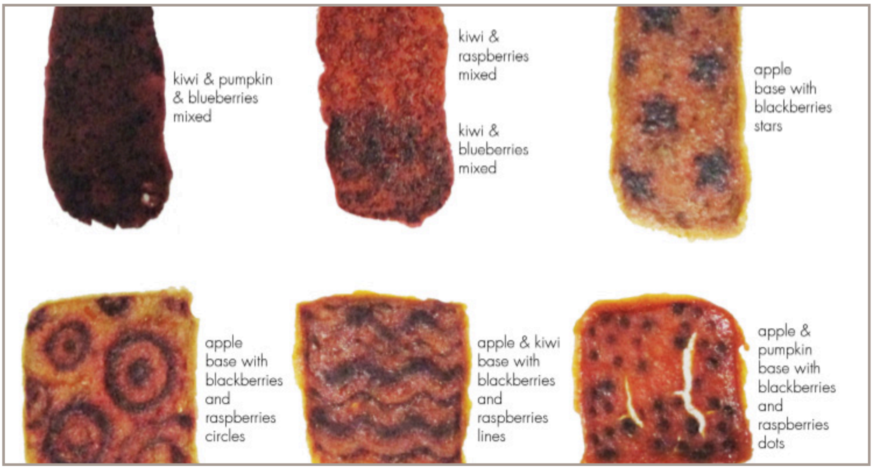
Stage One (1): The results of this stage derive from participant's experimentation phases. These phases are characterized by different operations in which the participants explored the behavior of the material by performing activities of tinkering. The different results were incremental and are part of the experiential knowledge that each team of participants gained by activating a physical interaction with the material. In this stage was visible how each team gained incremental experiential knowledge around the material by physical interaction. Achievements and failures were both critical parts of the process, and both provide direction and guidance on each step (Figure 7.19). The participants showed a transformation of perception about the study on every step of stage one. The questionnaires revealed how at the beginning of the experimentation phases and tinkering processes, the different participants felt frustration as their initial perception of how a material would behave was contrary to how the material actually behaved. The more iterations with the material and more knowledge were acquired by "hearing" the material, the less frustration occurred. At the end of stage one, each team of participants felt not only confident about the material samples but also engaged with it and with

Figure 7.19
Results of stage one: Experimentation phases through materials tinkering.

high levels of attachment to the project with a desire to carry on.

Stage Two (2): The results of this stage derive from participant's phase of improvement. Interventions characterize these phases on the samples which presented the higher potential in the previous tinkering phases. Possible surface treatments to improve resistance, texturizing and coloration, test for fire water and UV resistance, scratch resistance and tensile strength among others.
During this stage, participants changed the variables of the recipes, the size of the samples and explored basic transformation techniques according to the different behaviours of the material samples (Figure 7.20). The improvement of the material samples also occurs by adding specific design knowledge of composition and basic design principles. In this stage, the different designing abilities of the participants was reflected in the resulting quality of the samples. Their choices regard-

Figure 7.20
Results of stage two: Material improvements are visible in this stage.



ing a particular improvement were supported by inspirational boards as well as research directions discussed with the team of investigators.

Stage Three (3): The results of this stage were derived from the way each team of participants collected data during the previous stages through pictures, notes, videos, and annotations among others. At this stage, these elements become crucial as they reveal useful information and insights that could be important to build a story to accompany the DIY-Material. Collecting information during the different stages of the development creatively together with a declaration of a material vision helped to create a clear storytelling which is visible in the different videos each team of participants constructed. The majority of the teams added knowledge on visual communication to highlight their findings and experiences while developing a material (Figure 7.21). The majority of the materials were developed from locally avail-

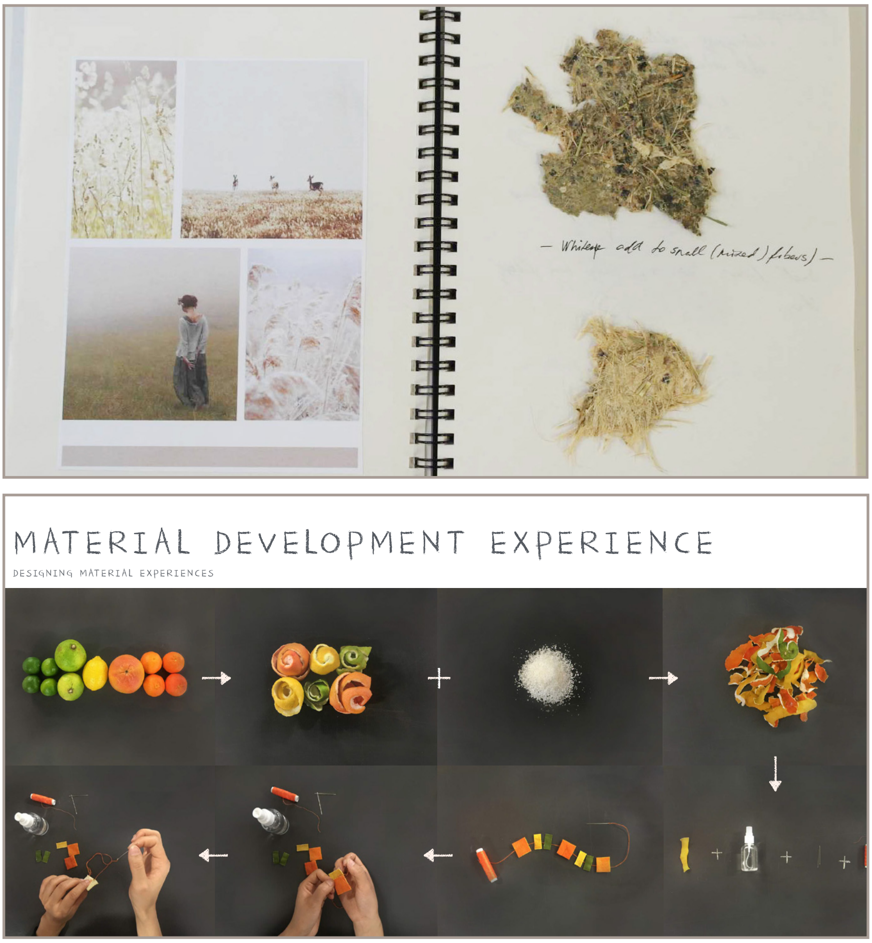


Figure 7.21
Results of stage three: Data collection and storytelling settings.

able resources transformed by the different tools available. The teams emphasize valuable imperfections, organic and uneven surfaces giving character to the materials. In this stage, the majority of the teams highlighted the visions for possible alternatives to apply in specific contexts. Those contexts sometimes are places were STEM materials have trouble to intervene.

7.3. Evaluation of materials with developed instruments

For each material, a similar evaluation to what was presented in chapter five was used (Figure 7.22). The conditions pentagon instrument and the weight of conditions instrument produced the quantitative analysis (see 5.2 on chapter five). Materials Source, Technology source and Craft source were taken out from the evaluation as this study was conducted as part of a course where those variables were under control. The quantitative data and the trend analysis doesn't get affected by not plotting those graphics. In figure 7.24 all 45 materials developed by the participants appear with their correspondent evaluation.

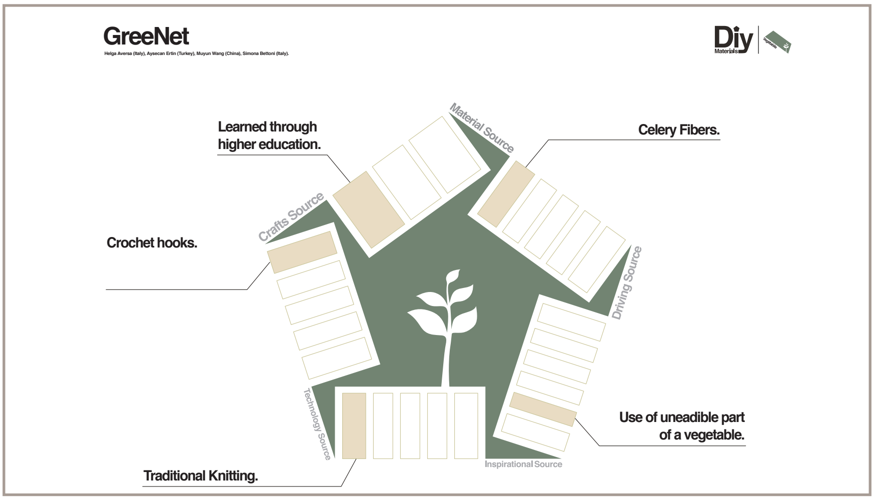


Figure 7.22
Conditions pentagon instrument example for a case belonging to Kingdom Vegetabile.

Similar to what happened while evaluating the case studies on chapter four, plotting the different materials into the tool showed similar trends. This confirmed how when placing a material sample into a particular kingdom, reveal similarities with other samples of the same category. In the kingdoms with more samples, the plotted graphics showed better trend (Figure 7.23). The evaluation was made once both editions of the course were concluded and without the partici-

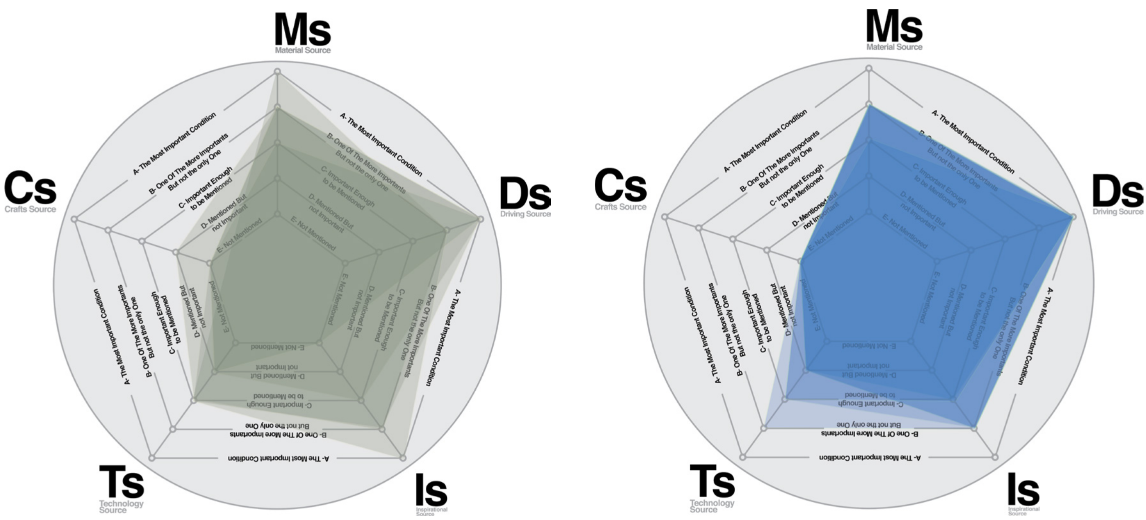


Figure 7.23
Left: (a) All cases from Kingdom Vegetabile evaluated and overlapped.

Right: (b) All cases from Kingdom Recuperavit.

pants. This setting allowed to evaluate the different samples produced by the participants with the same parameters of the previous study.

7.3.1. Analysing the driving source.

From this graphic it is possible to see how in Kingdom Vegetabile, similar to what appeared in the first study, the majority of cases were driven by an opportunity of some kind (figure 7.25). The tendency inside this kingdom - although in a minor scale due to the number of materials developed - is to move towards an opportunity to use bio-based elements with autonomy. The majority of cases also show the intention to replace another material by a self-made biopolymer. Kingdom Animale in this study tends to have a driver more connected with tackling a wicked problem.

In kingdom Lapideum, the trend behaves in a similar way to what happened in the first study where more than the 40% of the cases expressed an intention to search for a unique source of aesthetics.

When analysing kingdom Recuperavit it is possible to observe in this study also that around the 60% of the cases are driven by the idea to tackle a wicked problem so as to find more environmentally friendly solutions, recuperate waste from different sources and make more social awareness of the problems of materials misuse.

Figure 7.24
Basic digital chart for quantitative data.

	Material Source					Driving Source						Inspirational Source					Technology Source					Craft Source		
	Vegetal Source	Animal Source	Mineral Source	Recuperated Source	Mutant Source	A Particular Problem To Solve	To Tackle a Wicked Problem	To Overpass Material Aquisition Difficulties	An Opportunity of Any Kind	Go Beyond Industrial and Mass Customized Solutions	Search For a Unique Source of Aesthetics	Inspired by a Material Concept	Aesthetical Inspitarion	Inspired by a Materials Experience Vision	Inspired By The Way Somebody Did Something in the Past	Inspired By The Way Somebody Do Something	A Self Technological Development	Laboratory Aided	Industry Aided	Makers Development	Traditional Workshop	Learned Through Higher Education	Learned Through a Family of Craftspeople	Learned as a DIY Enthusiast
Greenet	■									■						■					■	■		
Leek Paper	■								■				■								■	■		
Dacus Chromatic	■								■				■								■	■		
Veggie Paper	■						■									■					■	■		
Flexbeet	■								■			■									■	■		
Refruit	■						■					■									■	■		
Ran	■								■			■									■	■		
Agroleather	■										■	■									■	■		
Catching Autumn	■										■	■									■	■		
Scent of Herbs	■								■			■									■	■		
EC Grass	■						■					■									■	■		
Pomelo Skin	■										■		■								■	■		
Peel it Off	■									■				■							■	■		
Sea Snow		■					■						■								■	■		
Porcaria		■					■					■									■	■		
It's Never to Lat(t)e		■					■					■									■	■		
Deconstruction of Milk		■							■			■									■	■		
Gelawool		■									■					■					■	■		
Breaknetic			■							■				■							■	■		
Plaster?			■								■	■									■	■		
Melach			■								■		■								■	■		
Nabatea			■								■	■									■	■		
Salt Sheets			■			■						■									■	■		
Makeup Saver			■							■						■					■	■		
Fruit Concrete				■			■						■								■	■		
Habitat				■			■								■						■	■		
C Shells				■			■					■									■	■		
Agrumiscela				■					■				■								■	■		
Shellboard				■						■		■									■	■		
Eggsperience				■						■						■					■	■		
Funco				■			■					■									■	■		
Marbile				■			■					■	■								■	■		
Comprastic				■			■			■				■							■	■		
Pizzaclay				■			■					■									■	■		
Silicork				■					■					■							■	■		
Cordeplastica				■			■								■						■	■		
Tea Cycle				■			■								■						■	■		
Butts Bunny				■			■					■									■	■		
Fluff				■					■			■									■	■		
Midas				■			■					■									■	■		
Co				■					■				■								■	■		
Fifty shapes of Ash				■					■				■								■	■		
CU Later					■					■		■				■					■	■		
Vague					■						■				■						■	■		
Vamoose					■					■				■							■	■		
Total of Cases	13	5	6	18	3	1	17	0	11	9	8	22	10	5	4	6	0	0	0	0	45	45	0	0
Percetage of all cases	26%	27%	21%	20%	20%	7%	15%	3%	26%	31%	24%	38%	24%	24%	5%	20%	25%	13%	17%	13%	35%	98%	5%	10%
Total cases Kingdom Vegetab	13					0	3	0	5	2	3	7	3	1	0	2	0	0	0	0	13	13	0	0
Total cases Kingdom Animale		5				0	3	0	1	0	1	3	1	0	0	1	0	0	0	0	5	5	0	0
Total cases Kingdom Lapideum			6			1	0	0	0	2	3	3	1	1	0	1	0	0	0	0	6	6	0	0
Total cases Kingdom Recuperavit				18		0	11	0	5	3	0	8	5	2	3	1	0	0	0	0	18	18	0	0
Total cases Kingdom Mutantis					3	0	0	0	0	2	1	1	0	1	1	1	0	0	0	0	3	3	0	0
Percentage by Kingdom Vegetabile						0%	23%	0%	38%	15%	23%	54%	23%	8%	0%	15%	0%	0%	0%	0%	100%	100%	0%	0%
Percentage by Kingdom Animale						0%	60%	0%	20%	0%	20%	60%	20%	0%	0%	20%	0%	0%	0%	0%	100%	100%	0%	0%
Percentage by Kingdom Lapideum						17%	0%	0%	0%	33%	50%	50%	17%	17%	0%	17%	0%	0%	0%	0%	**100%**	100%	0%	0%
Percentage by Kingdom Recuperavit						0%	**61%**	0%	45%	17%	0%	44%	28%	11%	17%	6%	0%	0%	0%	0%	100%	100%	0%	0%
Percentage by Kingdom Mutantis						0%	0%	0%	0%	**67%**	33%	33%	0%	33%	33%	33%	0%	0%	0%	0%	100%	100%	0%	0%

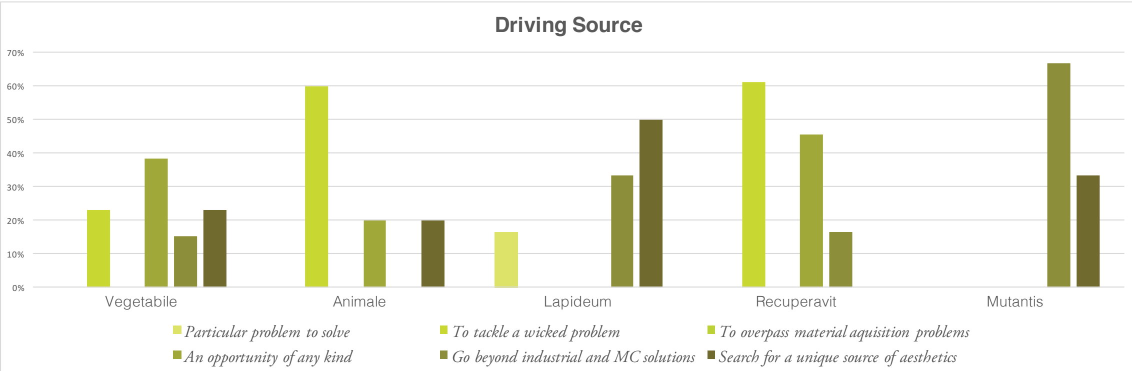


Figure 7.25
Weight of conditions for the driving source by kingdoms.

Kingdom Mutantis doesn't represent any significant data in this study as only three group of participants developed a material from this category.

7.3.2. Analysing the inspirational source.

54% percent of the cases analysed inside kingdom Vegetabile got inspiration from a material concept. Similar to what happened in the first study, a particular inspiration from some natural resources or the idea to bring elements from a particular element in nature developed a concept for the specific development. A similar trend occurs in Kingdom Animale where almost 60% of the cases seek inspiration from the nature of the resource and formulate a concept for a material development.

While in the first study in Kingdom Lapideum the trend showed inspiration through aesthetics, in this study the higher value was also connected with a material concept. This is possible also by the unique setting of the study as all participants were design students and therefore, keen to seek inspiration by developing a material concept. Kingdom Recuperavit showed the same trend having the material concept at the top of the list of inspirational sources for the participants of the study (Figure 7.26).

7.4. Findings and validation of hypotheses.

The study in the form of a course in the two editions produced high-quality materials considering time and infrastructure limitations. All the teams followed the path according to the structure of the study

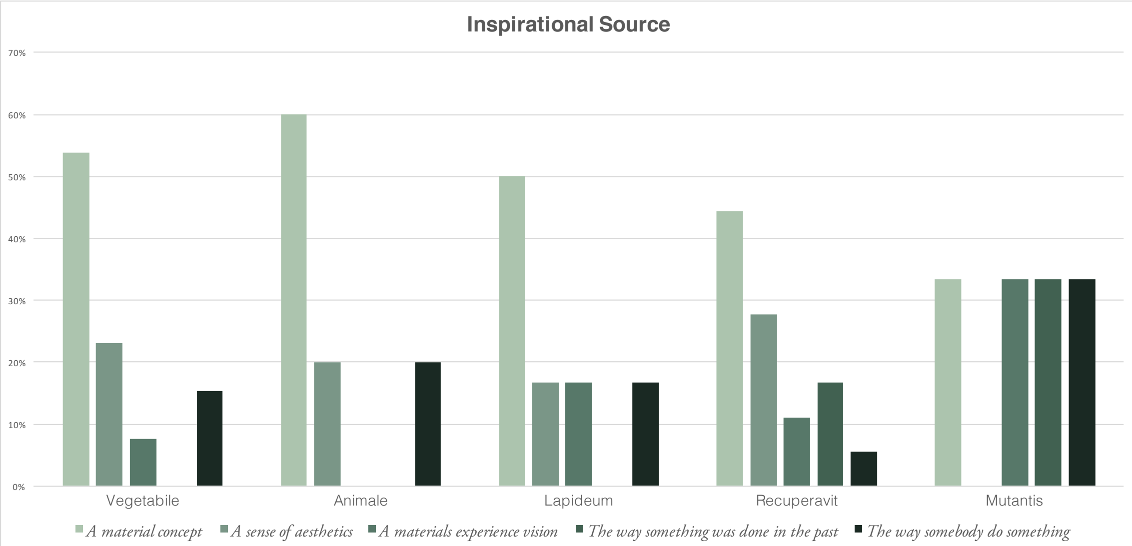


Figure 7.26
Weight of conditions for the inspirational source by kingdoms.

and arrived at a material sample at the end of the course. The first test hypothesis **(TH1)** which suggested that *There is a relationship between knowing how to craft things and materials development*, was satisfactorily tested. The performance of all the teams was not equal and although the majority of participants were engaged with the course, the fact that this was an elective course inside the MSc. programs meant that some participants dedicated less time and resources, achieving fewer quality results. The theoretical stimuli responded satisfactorily, as all the different teams expressed in their final deliveries in random order, the diverse knowledge acquired during the sessions and applied to the project. One valuable insight that became more and more evident during the study was the struggle of individuals when they lack the training of crafts of any kind. The teams with participants who were weak in crafting, making or "getting dirt with their hands," produced weaker materials compared with the ones where the team was confident in handwork.

The second test hypothesis **(TH2)** suggested that *Starting a material development from a particular source has an effect on the final material developed*. During the two editions, the importance for teams to set a target kingdom for their projects in the beginning, became apparent. They not only observed and analysed the cases on the DIY-Materials database but added new ones. By understanding the differences between each kingdom, the different teams shared information with others and benefited from collective learning that pushed the experi-

mentations to a higher unexpected level.
During the first edition, a problem emerged regarding Kingdom Mutantis. No participant wanted to deal with Mutantis based on its perceived complexity. Mutantis kingdom became mandatory for the second edition, but it was difficult for the participants to address, mainly because of the limitations regarding infrastructure and access to specific tools. Not all of the students knew programming, interaction design or had access to fab labs. Some became intimidated by the process and requested to be shifted to another kingdom.

During the study, the different debates and reviews of the projects showed kingdom interrelationships. Different projects dealing with ingredients such as fruit peels of fish skins, struggle to stick to a particular kingdom. Depending on the core motivation (if it is possible to measure), the project could be seen from Animale and Vegetabile kingdom or from Recuperavit kingdom as well.

Our third test hypothesis **(TH3)** suggested that *DIY-Materials were the result of motivations other than what STEM materials commonly have. Not regarding performance and capabilities, but regarding what they have to offer to potential users*. From the different materials produced by the participants of the two editions of the course, it is possible to find that thirteen projects from Kingdom Vegetabile, five projects from Kingdom Animale and fifteen projects from Kingdom Recuperavit deal with the organic matter. There is a tendency to go towards bio-based materials as all of the teams preferred to use what the earth already provides, either as a renewable source or as a recuperated one and create products with less impact to the different ecosystems. This finding could be used to validate our third hypothesis. The same happens to all eighteen projects inside the Kingdom Recuperavit which were driven by the idea to manage resources smartly, finding alternatives to raw materials by mining the city. All the different projects inside this kingdom apart from their specific individual motivation, share the idea of going over the city to hunt for resources.

7.5. Conclusions

From the third study, it is possible to conclude that the level of competencies of the participants who enter into a DIY-Materials development is vital. It may not be crucial in the development of a material sample but is evident in the participants' ability to sensibly and sensitively work with matter. Developing a collection of material samples, improving features and applying design related knowledge notably improve the quality of the DIY-Material at the end of the development. Participants with inadequate knowledge of crafts have shown a weak material development in the study compared with the ones who are more craft-oriented.

The study also revealed how important it is for a material to tell a story. The different phases of the story must be coherent and according to the different media used to communicate the material experience vision.
The study showed that the more attention a team dedicated to the achievement of coherent storytelling, a better result of the whole project arrived. In other words, the weakness of the different material samples at the end of the study was due to the incapability of the participants to tell the whole story of the intention to develop a material out of a particular source. The story is not only expressed by a video or a diary; the samples were also elements carrying the different stories behind the development. The material samples were the ones able to support the future visions for an application when they embedded storytelling in their surface by showing scars, blends and other elements of the tinkering process in a proper way. When the participants acknowledged what the material could show, they highlighted a particular feature during the presentation of the final result. This story allows the showcasing and presentation of the material to possible stakeholders helping to push the material onto a higher level.

The highest number of samples produced by participants appeared under Kingdoms Vegetabile and Recuperavit. It demonstrates a higher tendency to use the local resource. This insight can be seen as a limitation as it conditions a type of result but can also be seen as an advantage as our societies tend to look for local, sustainable solutions inside circular economies.

The study was developed to test this research and was not intended for educational purposes. Undoubtedly, the participants acquired skills through this type of practice-based project, gaining knowledge and sensibility to matter, but the goal of the study was to see the possibility of pushing for the self-production of a material. Auto production could also present new ideas and new approaches alternatively to what the industry commonly produces. This approach could be later taken on by industries to move ahead. It is Important to include here that while evaluating the different materials produced by the participants with the same tools form the first study, the behaviours of the materials inside each kingdom tend to go in the same direction. More robust studies can be conducted in the future with these tools to observe if the trends continue.

Chapter Eight

Fourth Study: DIY-Materials development level two

In the previous chapter, the aim was to validate Test Hypotheses **(TH1, TH2 and TH3)**. The different outcomes provide qualitative data that show how someone with an ability to craft, with some particular guidance is able to propose alternative material visions to what is usually proposed by STEM sciences. This chapter presents a fourth study which was proposed after interpreting and understanding the different findings from the third study. The aim of this study was to prepare a small group of participants who could concentrate for a longer period of time in the material development, achieving more profound results. The different outcomes of this study are a combination of quantitative and qualitative data about a developed DIY-Material. A deep understanding of the material sample, together with a focus on a particular necessity or opportunity to tackle, could take the material development to a higher level. This study provided crucial information about how these materials can be developed by different stakeholders in different context and environments. The subject is further explored in **chapter nine**.

8.1. Selection process for level two

Testing the DIY-Materials theory and hypothesis with such broad multicultural and heterogeneous group of designers coming from all five continents provided sufficient amount of data and outcomes. However, the level of the materials samples was still closer to an intellectual exercise to provide a statement (not trustable in terms of performance), than something that could have an impact on the market in a near future (trustable in terms of performance). To take the research to the next level, different participants who attended the first study were selected for this study. The participants who developed the most promising DIY-Materials samples had the possibility to develop their Master of Science thesis in the related area. The participants accepted and agreed to follow the project under certain constraints and guidelines. Each one of the projects addresses a particular issue that was unsolved or remains unanswered by the previous study. The participants addressed topics such as characterization of the materials, scalability, and applicability of the DIY-Materials theory in contexts outside the academic environment.

8.2. Incremental setting of the fourth study

The initial setting of the doctoral research as is explained in the objectives in **chapter one** was to develop a theoretical framework which allows the practice of DIY-Materials to become available and implemented by a broader design audience. Topics related to circular economy and social innovation connected with the third macro area of research were still unexplored. The different considerations on how to achieve it from a "materials and design" approach needed a structure of research allowing to construct from what was already tested but without repetition. A standard incremental iterative process in design development cycles known as the spiral model (Lidwell, Holden & Butler, 2010 pp. 79) was adopted. This process works for the development of a specific topic, completing it through an increasing percentage in every iteration. By adopting this basic method, every thesis development will provide a particular input to the study and it will add knowledge to the following thesis work incrementing the possi-

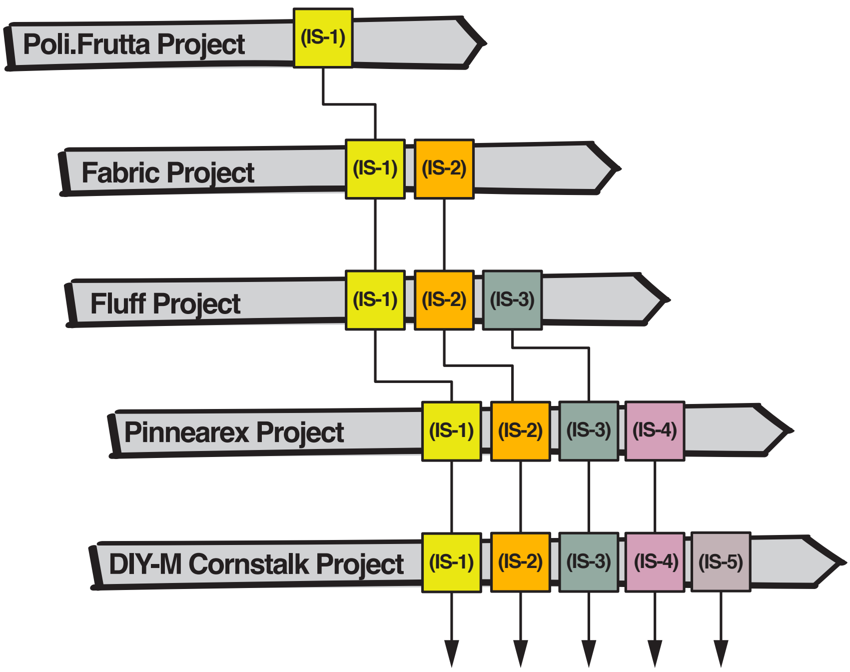


Figure 8.1
Incremental setting for DIY-Materials development level two.

bility to consolidate a specific research topic. To this aim, each project focuses on one particular issue. The first thesis work passed knowledge and insights to the second, and the second added knowledge and submitted to the third and so forth. By doing so, participants were aware of the previous findings from the others, and could include some of them in their research to push forward their projects.
The final result of this study reflects in a series of steps relevant for the whole DIY-Materials development theory (Figure 8.1). In **chapter nine**, it is possible to observe how the different stages and theoretical stimuli of the third study, together with the further steps followed by the thesis work of the fourth study, build a roadmap for the development of a material from a design perspective. This type of method is still being applied in the thesis work of other current projects that are not part of this dissertation. Probably they may add or modify the DIY-Materials roadmap in the future.

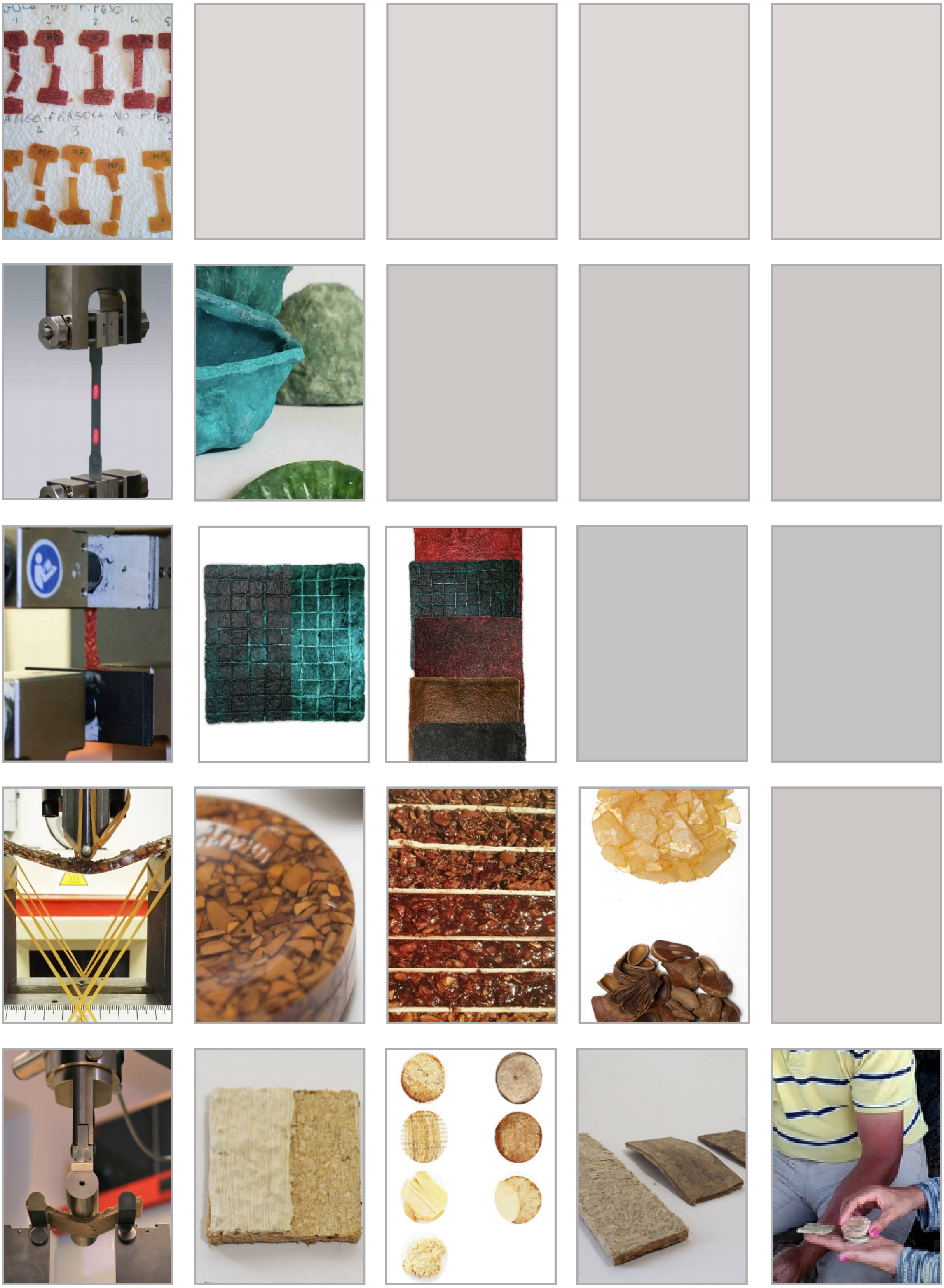
The different topics each work of this study was requested to address are as follows (Figure 8.2):

8.2.1. Characterization of the materials (The Poli.Frutta Project)
- **Incremental Step (IS.1)**
8.2.2. Transformation and shape giving (The Fabric Project)
- **Incremental Step (IS.2)**
8.2.3. Expressive-sensorial development (The Fluff Project)
- **Incremental Step (IS.3)**
8.2.4. Setting for material circularity (The Pinearex Project)
- **Incremental Step (IS.4)**
8.2.5. Setting for social innovation starting from the material (The DIY-Cornstalk Project)
- **Incremental Step (IS.5)**

8.3. The study

Study four was conducted within the Master of Science of the school of design at Politecnico di Milano during the academic year 2017/2018. The Participants came from the Master's courses in *Product Design for Innovation, and Design & Engineering*. The study had a duration of twenty weeks. Each participant reported weekly the advancements in individual and collective sessions with the aim to share and discuss advancements regarding the material experimentation phases.

Figure 8.2
On the next page.
Incremental steps added by each project.
From left to right:
IS.1
IS.2
IS.3
IS.4
IS.5



Not all projects started and ended at the same time. Each project had a different level of complexity and was scheduled independently. However, the weekly reports and submissions were maintained collectively and with fixed schedule to assure a crosspollination of findings, and to fine tune each incremental step explored by each participant.

8.3.1. Design Process

The Incremental step study was divided into two main stages:

Stage One (1) Designing materials experiences: The same methodology of the third study described in **chapter seven** occurred in this phase. The tinkering process and evolution of the material samples were condensed into the first ten weeks. The difference from what occurred in the previous study is that in this study, the participants reported advancements twice a week. The first advancement sessions were held individually and the scope was to identify gaps, directions and solve specific problems related with the experimentation. The second advancement sessions were collective with all participants involved. The aim of this second advancement sessions was to share the process, highlight insights and receive collective feedback.

Stage Two (2) Incremental step focus: Once the materials samples achieve the desired level for the particular aim of the project, each participant focused on the specific task and developed an individual schedule. In this phase, only the collective sessions were kept in schedule and the participants reported specific advancements of their incremental step task. When a participant completed the assigned incremental step, the whole collective session was devoted to knowledge transfer. By doing this, the results of the incremental step became available for the rest of the participants to include it their project when needed. Once each project achieved the desired level regarding the specific focus of the incremental step, the material storytelling and reporting documents were written and developed individually.

8.3.2. Deliverables

To better address the research purposes of this study, a series of deliverables were requested to the participants related to the stages of the design process and divided in **(A)** DIY-Material samples, **(B)** DIY-Materials written report, **(C)** a DIY-Materials video and **(D)** incremental step report (Figure 8.3).

Figure 8.3
Deliverables requested to each participant.
(a) DIY-Material samples.
(b-c) DIY-Materials written report.
(d) DIY-Materials video.
(e-f) DIY-Materials incremental step report.

8.4. Results

In the following pages, it is possible to find a brief description of each thesis work which made part of this study. Each work will highlight the specific setting for the incremental knowledge that will pass to the following ones. Each incremental knowledge step will be marked with the symbol for Incremental Step **(IS)**. This knowledge will appear embedded in the next thesis description and will be part of the discussion at the end of the chapter. In order to understand each incremental step, a brief description of the thesis setting with a background of the development and how the particular issue was addressed will be explained in this chapter to help understand the incremental process. For more information about the specific thesis work, refer to the bibliography.

8.4.1. The Poli.Frutta Project

Thesis Setting: The main topic to address was to achieve a characterization of a DIY-Material. The brief suggested a way to find the substitution of plastic. What will happen when suddenly the world supply

Figure 8.4
Poli.Frutta Material Board.

of plastic ends? How can designers address the issue?

Background

The background makes part of a current topic and deals with the fact that plastic materials, being one of the significant discoveries of modern science, have taken human civilization further. Undoubtedly many applications which consider the characteristics of each polymer correctly during the whole cycle improve the way of life. By contrast, wrong applications of polymers, specifically oil-based commodity polymers (PP, PE, EPP, EPS, PET, PMMA, PUR, PVA, and PVC) are damaging the ecosystems.
According to the work of Marcus Eriksen called "Plastic Pollution in the World's Oceans", the number of plastic particles floating in the sea is estimated to be at least 5.25 trillion plastic particles weighing 268,940 tons (Eriksen et al., 2014 p. 7). Such data serves more than just a warning to change behavior towards a more sustainable society. It is an invitation to act. People from different fields are making their contribution to solving the problem. So can designers. Designers could help change people's behavior by rethinking the way things are made. Starting with a material development is quite a challenge for a designer, but could also be a significant contribution to tackle

the environmental issue. Designers, through their actions, can make significant changes in the society. For example, the three chasing arrows of the universal recycling logo, which reflects the idea of the three R law "reduce, reuse and recycle" designed by Gary Anderson in the 1970's inspired by the cycle of water, suddenly became one of the most recognizable logos of our time.
In recent years, more designers are aware of the different environmental issues to tackle and are proposing different creative alternatives to deal with the problem as is stated more clearly in **chapter four**.

Beth Terry in her book Plastic Free (2012), suggests another three R's to the equation. Refuse (not using plastic packaging), Reduce (Not acquiring unnecessary goods), Reuse (Extend life of existing products), Recycle (Dispose properly separating materials), Repair (Give extra life to objects when possible) and Replace (Acquire products made out of other materials but with similar and enhanced properties and qualities). The last one is one of the primary drivers of the DIY-Materials theory and is rooted in the idea of a material surrogate as explained in **chapter three**. The concept of a surrogate in the early years of the materials science development was not only connected with the idea of a substitute, but was also perceived as a substitute of lower quality (Rognoli & Levi, 2005, p. 15). DIY-Materials, on the other hand, could become surrogates of materials that in this particular case are damaging the planet embedded in wrong applications and could be perceived positively.

Figure 8.5
Samples made out of different fruits and peels.

Addressing the problem

In 2011, OI-Ying Kwong published a User's friendly Bio-Plastic Handbook containing a series of formulas to make DIY samples of different biodegradable polymers[1]. The booklet is one of many available resources to understand how to work with these types of sources. The value of this publication is that the explanation of each experiment and the accuracy of the measurements make the replication process possible. The designer took this book as a starting point. She followed all steps of the course of the third study, to obtain through tinkering processes and following the MDD methodology, the first set of samples. This first collection behaves, looks and smells similar to the ones created by fruit leather Rotterdam from case studies explained in **chapter four**. Different samples made out of Mango, Peach, Red Grape, Strawberry, Banana, and Apple, composed the first set of samples, while mixtures between the different fruits comprise the second set. Once evaluated, the best samples regarding apparent mechanical and aesthetical behavior (Figure 8.5), - the ones made out

1. Published through the digital publishing platform ISSUU https://issuu.com/oi-ying/docs/bio-plastic_handbook2

Figure 8.6
DIY-Materials characterized in the Giulio Natta laboratory of Politecnico di Milano.

of Mango and Strawberry moved to the next step: Initial characterization in a lab.

Characterization of DIY-Materials (IS-1)

The laboratory where Giulio Natta developed chemical processes of stereospecific polymerization and developed the isotactic polypropylene - achievements that won him the Nobel prize in chemistry in 1963 - was the scenario for the DIY-Materials characterization research (Figure 8.6). The self-produced material samples were tested to obtain initial data towards a proper characterization. The different tests performed were as follows:

Weight loss

How much humidity (water) can each sample absorb? Test related to the average loss of moisture when the samples are exposed to a drying process. It is one of the critical assessments to understand the biodegradation of biopolymers under aerobic and anaerobic conditions (Kallel et al., 2015). The materials with a mixture of both fruits showed a slower weight loss, suggesting that they would take a longer time to biodegrade in aerobic conditions (Figure 8.7).

Apparent density

According to the ASTM D1895 - 17 which is the Standard Test Methods for Apparent Density, Bulk Factor, and Pourability of Plastic Materials, measuring apparent density provides useful indexes of the performance of plastic materials concerning their handling in packaging and fabrication. Apparent density helps to measure the fluffiness of a material and in this case, reveal possibilities for further applications. The tests conducted show a good behavior of both strawberry and mango samples. Further studies could conclude (if the tendency maintains) a possibility of these materials to become surrogates of different packaging related applications (Figure 8.8).

Figure 8.7
Weight loss data of Poli.Frutta obtained in the characterization phase.

Poli.Mango composed by

73 g mango

20 g Strawbwrry

1 spoon starch

(5 g) dissolved in 4 spoon water (8 g)

Total weight 106 g

14,5320 g of weight after dessication = -86,29%

Poli.Fragola composed by

40 g Strawbwrry

1 spoon starch

(5 g) dissolved in 4 spoon water (8 g)

Total weight 53 g

4,0491 g of weight after dessication = -92,36%

Test for Weight Loss

	Weight 1 (g)	Weight 2 (g)	Weight 3 (g)	Weight 4 (g)	Weight 5 (g)	Weight 6 (g)	Weight 7 (g)
Poli.Mango							
C1 (Every 60')	0,1738	0,1655	0,1641	0,1633	0,,1625	0,162	0,1617
Weight Loss		*-4,78%*	*-0,85%*	*-0,49%*	*-0,49%*	*-0,31%*	*-0,19%*
C2 (Every 60')	0,1433	0,1373	0,1363	0,1361	0,1355	0,135	0,1346
Weight Loss		*-4,19%*	*-0,73%*	*-0,15%*	*-0,44%*	*-0,37%*	*-0,30%*
C3 (Every 60')	0,2519	0,237	0,2352	0,2326	0,3215	0,2304	0,2303
Weight Loss		*-5,92%*	*-0,76%*	*-1,11%*	*-0,47%*	*-0,48%*	*-0,01%*
C4 (Every 60')	0,237	0,2236	0,2213	0,2201	0,2191	0,218	0,218
Weight Loss		*-5,65%*	*-1,03%*	*-0,54%*	*-0,45%*	*-0,50%*	*0,00%*
C5 (Every 60')	0,2539	0,2386	0,2357	0,2345	0,2334	0,2326	0,2321
Weight Loss		*-6,03%*	*-1,22%*	*-0,51%*	*-0,47%*	*-0,34%*	*-0,21%*

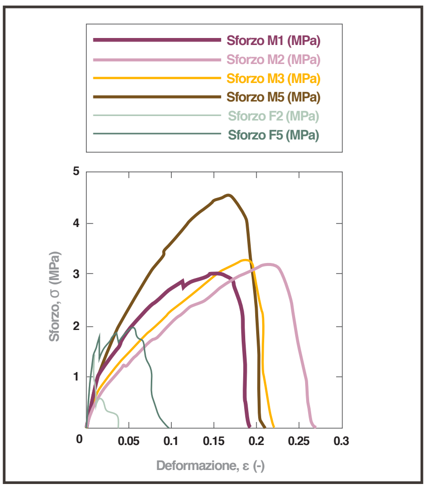
Poli.Fragola							
C1 (Every 60')	0,1474	0,1408	0,1392	0,139	0,1385	0,1385	0,1379
Weight Loss		*-4,48%*	*-1,14%*	*-0,14%*	*-0,36%*	*0,00%*	*-0,43%*
C2 (Every 60')	0,1239	0,1195	0,118	0,118	0,1175	0,1174	0,1169
Weight Loss		*-3,55%*	*-1,26%*	*0,00%*	*-0,42%*	*-0,09%*	*-0,43%*
C3 (Every 60')	0,1376	0,1318	0,1305	0,1302	0,1296	0,1293	0,129
Weight Loss		*-4,22%*	*-0,99%*	*-0,23%*	*-0,46%*	*-0,23%*	*-0,23%*

Tensile testing

Tensile properties often are measured during the development of new materials and processes, so that different materials and procedures can be compared. The strength of a material is the primary concern, but information regarding elongation, toughness, and fracture are also measured. In the case of Poli.Frutta the tests were performed only to materials dried under atmospheric conditions. The materials dried in an oven didn’t provide useful data. Here the tests revealed a better behavior of the samples made out of a mix of both fruits in comparison with the ones made only with strawberry or mango (Figures 8.9 - 8.10).

Apparent Density (g/cm3) - d=m/V								
		Mass 1	**Mass 2**	**Mass 3**	**Mass 4**	**Mass 5**	**Mass 6**	**Mass 7**
	Poli.Mango							
	C1 (Every 60')	0,1738	0,1655	0,1641	0,1633	0,,1625	0,162	0,1617
Volume (cm3)	*0,11691*	*1,45*	*1,38*	*1,37*	*1,37*	*1,36*	*1,35*	1,35
	C2 (Every 60')	0,1433	0,1373	0,1363	0,1361	0,1355	0,135	0,1346
Volume (cm3)	*0,11276*	*1,27*	*1,22*	*1,21*	*1,21*	*1,20*	*1,20*	*1,19*
	C3 (Every 60')	0,2519	0,237	0,2352	0,2326	0,3215	0,2304	0,2303
Volume (cm3)	*0,18111*	*1,39*	*1,31*	*1,30*	*1,28*	*1,28*	*1,27*	*1,27*
	C4 (Every 60')	0,237	0,2236	0,2213	0,2201	0,2191	0,218	0,218
Volume (cm3)	*0,1606*	*1,48*	*1,39*	*1,38*	*1,37*	*1,36*	*1,36*	*1,36*
	C5 (Every 60')	0,2539	0,2386	0,2357	0,2345	0,2334	0,2326	0,2321
Volume (cm3)	*0,15719*	*1,62*	*1,52*	*1,50*	*1,49*	*1,48*	*1,48*	*1,48*
Avg. Density	1,44							

	Poli.Fragola							
	C1 (Every 60')	0,1474	0,1408	0,1392	0,139	0,1385	0,1385	0,1379
Volume (mm3)	*0,12302*	*1,20*	*1,14*	*1,13*	*1,13*	*1,13*	*1,13*	*1,12*
	C2 (Every 60')	0,1239	0,1195	0,118	0,118	0,1175	0,1174	0,1169
Volume (mm3)	*0,88847*	*0,14*	*0,13*	*0,13*	*0,13*	*0,13*	*0,13*	*0,13*
	C3 (Every 60')	0,1376	0,1318	0,1305	0,1302	0,1296	0,1293	0,129
Volume (mm3)	*0,99098*	*0,14*	*0,13*	*0,13*	*0,13*	*0,13*	*0,13*	*0,13*
Avg. Density	0,49							



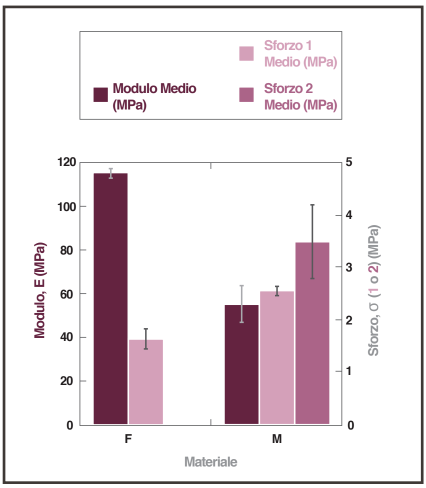


Figure 8.8
Apparent density data of Poli.Frutta obtained in the characterization phase.

Figure 8.9
Graphic plot of the of Poli.Frutta tensile testingduring characterization phase.

Figure 8.10
Tensile tests data of Poli.Frutta obtained in the characterization phase.

Sample	Thickness (mm)	Width (mm)	Lenght (mm)	Section (mm^2)	E (MPa)	Strain 1 (MPa)	Strain 2 (MPa)
Tensile Testing							
	Poli.Mango						
	0,36	4,4	22	1,8773	69,15	2,85	3,03
M1	*0,44*						
	0,48						
Avg.	*0,4266*						
	0,58	4,4	22	2,5813	40,9	2,44	3,19
M2	*0,6*						
	0,58						
Avg.	*0,5866*						
	0,42	4,4	22	1,8626	55,72	2,38	3,27
M3	*0,43*						
	0,42						
Avg.	*0,4233*						
	0,26	4,4	22	1,232	40,8	3,66	4,5
M5	*0,26*						
	0,32						
Avg.	*0,28*						
Avg. F					51,6425	2,8325	3,4975
St. Dev.					13,6149	0,5898	0,6757
	Poli.Fragola						
	0,32	4,4	22	1,408	115,12	1,501	
F2	*0,32*						
	0,32						
Avg.	*0,32*						
	0,46	4,4	22	1,9653	117,12	1,77	
F5	*0,41*						
	0,47						
Avg.	*0,4466*						
Avg. F					116,12	1,6355	
St. Dev.					1,4142	0,1902	

Sensorial Characterization
Sensorial evaluation was performed by all projects. In this case is visible in Figure 8.11.

DIY-Material as a surrogate for?
This thesis work aimed to allow the student to achieve a higher level of knowledge about the material. Bringing the samples to a proper laboratory to perform standard tests for materials characterization was a step further compared to what was achieved in the different materials developed in the second study. It was not the intention of the thesis to find a material that could replace a commodity polymer, but instead, it served to validate the hypothesis of whether or not a DIY-Material could obtain quantitative data and if that data can draw upon initial thoughts about possible uses for the material. In this

particular case, the bioplastic material could replace another material that is misused in different applications that harm the environment, at some point in the future.

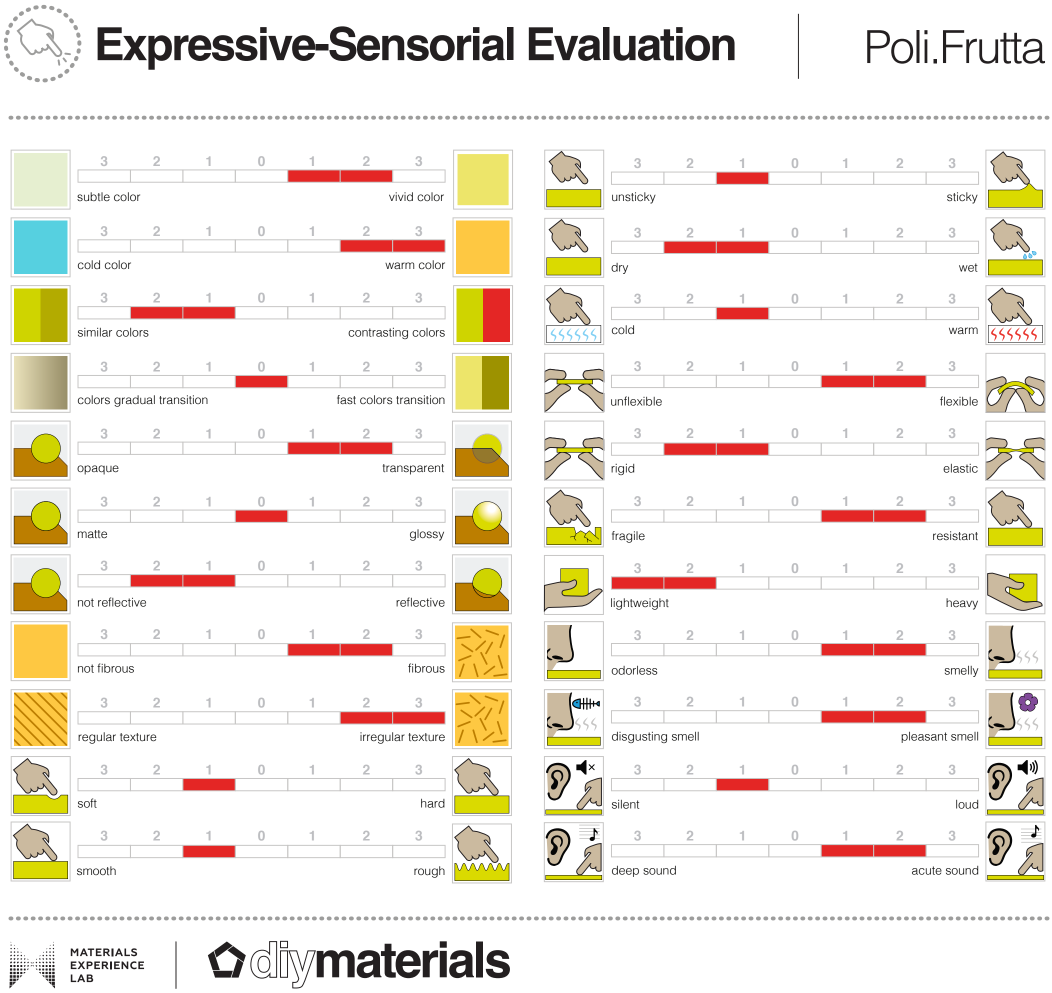


Figure 8.11
Sensorial evaluation data of Poli.Frutta obtained in the characterization phase.

For further information regarding the project and detailed analysis on the explored topics, refer to (Giani, 2017).

8.4.2. The Fabric Project

Thesis Setting: this research evolved from the project Fluff explained (See appendix 02), which is a material created by drying clothes in a dryer. It is one of the two works in this chapter developing the same topic but producing different incremental steps **(IS)**. For this project, the designer was asked to perform an investigation into the possibilities of shaping the material. The problem to tackle is a result of

Figure 8.12
The Fabric Project Material Board.

one of the issues discussed in the previous chapter where almost all DIY-Materials developed during the third study appear in the same bi-dimensional shape. Is it possible to shape a material with standard manufacturing processes?

Background

Fluff belongs to Kingdom Recuperavit which is a kingdom where waste and leftovers become resources. During the standard daily procedure of maintenance of the different self-service laundries, it is common to find a wool-like matter of 20 centimetres in diameter on average. After a week, a whole bag of this matter is filled and thrown away in the garbage. The designer's motivation for this project comes from her personal experience dealing with this matter through her family business. After understanding through the third study how such material can become a valuable resource, she decided to go further and devoted applied research. Industrial dryers, different from household ones, require cleaning of the filter on a daily basis to ensure the correct functionality. The wool-like matter that comes out of this filter is an accumulation of the different fibers from the drying pro-

Figure 8.13
Development of the Fluff material.

cess. Although the clothes have different compositions regarding the fibers, it is more likely to find natural ones (Cotton, wool), as they are easy to lose from the clothes. Synthetic fibers are also present but in less quantity. It is possible also to obtain human hair or feathers interlaced in the sample.

Continuing with the previous thesis background where there is a need for new materials that could replace the polymers in uses that are not suitable for the environment, the designer began a series of experiments aiming to create a kind of bio-polymer where the primary constituent are the resources of the industrial dryer. Following the experimentation steps of the third study to obtain the initial materials, the student arrives at a series of samples composed of the fluff, lemon, sugar, starch, and water. The more fluff into the mixture, the more elastic and malleable (Figure 8.13).
During the first part of the project the designer tuned up the material samples with the different combination of ingredients. After performing user studies to understand the perception of the material, she began a qualitative evaluation of the material samples according to the methodologies of the course of previous study. Following the steps of the Poli.frutta project, the designer fine-tuned the recipe to finally choose a material for testing. The new material is called felt stone.
To this new composition, the designer executed some characterization tests. The selected lab tests for this material were:

Determination of tensile properties
According to the ISO 527, this test allows gathering information about the tensile strength, tensile modulus and other aspects of the tensile stress/strain relationship under defined conditions. The results of the test are shown in figures 8.14 and 8.15 a.

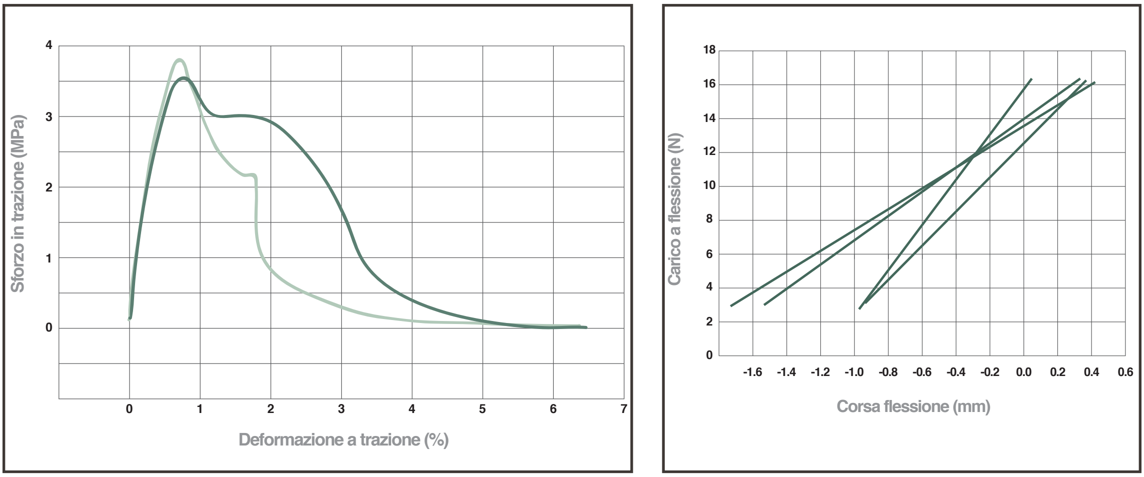
Figure 8.14
Tensile properties data of The Fabric Project obtained in the characterization phase.

Tensile Properties (ISO 527)

	Yield Strenght (Mpa)	Ultimate Tensile Strenght (Mpa)	Stress at Break (Mpa)	Stress at x % Strain
Sample 1	3.85	3.85	1.69	1.97
Sample 2	3.62	3.62	0.32	2.12
Sample 3	3.51	3.51	0.19	2.02
Avg.	3.68	3.68	0.94	1.99
Std. Dev.	0.2391	0.2391	1.0612	0.0358
Maximum	3.85	3.85	1.69	2.02
Minimum	3.51	3.51	0.19	1.97
	Strain at Break (%)	**Nominal Strain (%)**	**Strain at Yield (%)**	**Strain at Strenght (%)**
Sample 1	1.68	1.65	0.68	0.68
Sample 2	1.82	1.87	0.67	0.67
Sample 3	4.40	2.72	0.67	0.67
Avg.	3.04	2.19	0.67	0.67
Std. Dev.	1.9242	0.7557	0.00385	0.00285
Maximum	4.40	2.72	0.68	0.68
Minimum	1.68	1.65	0.67	0.67

Flexural properties
Following the ASTM D 790, the designer performed a test to obtain information related to the young modulus as seen in figures 8.15 b-c.

Ash content
According to the ASTM D2584, it is possible to do a test taking the



Flexural Properties (ASTM D 790)		
	Modulus (Young Modulus Automatic) (Mpa)	**Modulus (Young Modulus w/Flexure Strain - 0.35 mm) (Mpa)**
Sample 1	1280	1293
Sample 2	581	282
Sample 3	1190	1213
Avg.	931	787
Std. Dev.	493.84	715.01
Maximum	1280	1293
Minimum	581	282

The Fabric Material composed by

2 Spoons of Fluff

4 Spoons of Water

1 Spoon of Flour Type "00"

2 Teaspoons of Carob Flour

3 Teaspoons of Sugar

2 Teaspoons of Vinegar

material to 550ºC to determine harmful substances inside the material as well to find the presence of fillers. The analysis concluded positively, assuring the absence of hazardous substances in the samples. With a density of 1,3 gr/cm3 and a young modulus of 787 MPa, it behaves similarly to starch-based thermoplastics (TPS) and the Polyhydroxyalkanoates (PHA, PHB).

Figure 8.15
Above left:
(a) Tensile properties plot
Above Right:
(b) Flectural properties plot.
Below:
(c) Flectural properties data.

Sensorial Characterization

Sensorial evaluation was performed by all projects. In this case is visible in figure 8.17.

Forming a DIY-Material (IS-2)

The tinkering process of this project got an extra component to research and deals with finding which different forming techniques are suitable to give shape to the material. The designer started an exploration with the various methods of industrial manufacturing that could be made with DIY tools. At the end of the research, she was able to perform manufacturing tests with FDM, Injection, extrusion, compression, thermoforming, machining as seen in figure 8.16.

Forming results

Fused deposition modelling: It is possible to simulate the heating of a filament of the material and creating a DIY nozzle to deposit the material in layers like a standard 3D printer with FDM technology. Some adjustments and settings of a hacked machine will produce better results, but the principle shows feasibility.

Injection: Similar to what happens in the previous experiment, adding the material through an injection hole inside a mold, it is possible to obtain the desired shape. For obvious reasons the injection process made with DIY tools didn't achieve fidelity of the forms but as a starting point shows possibilities to work with this technique.

Extrusion: With different nozzles and uniform transportation of the material through the barrel, it was possible to obtain solid extruded shapes.

Compression: This is probably the most suitable technique for this type of material. At the moment where the upper part of the mold pressures the material, a uniform distribution of the material occurs.

Thermoforming: After a process of compressing a uniform sheet of the material, it is possible to heat and form it accordingly to the desired shape. It is essential to consider the height of the mold, as for the moment, the material composition does not behave like a standard polymer for thermoforming like PS or PE.

Machining: Removing material from a solid block is possible and produces a residue that can be transformed again into a felt block. It is necessary to perform a previous compression process to avoid the presence of air holes inside the material. These holes appear during the machining process damaging the sample.

Figure 8.16
Above:
(a-b) Characterization tests.
Middle:
(c-d) Injection and Extrusion tests.
Below:
(e-f) Machining and Thermoforming tests.

DIY-Material Manufacturing?
This work aimed to allow the designer to achieve a further level of knowledge about the DIY-Material and its capabilities to produce form.
The incremental work of experimenting, tinkering, qualitative evalua-

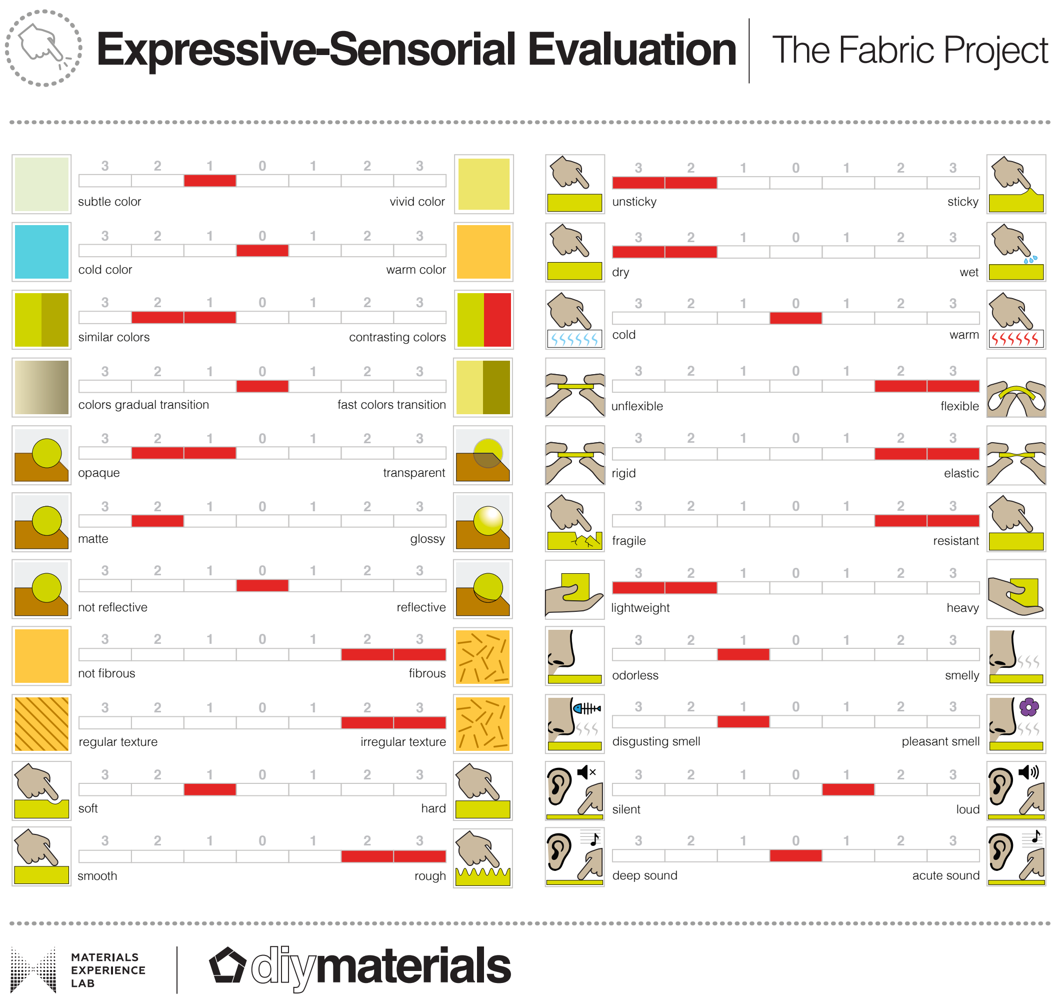


Figure 8.17
Sensorial evaluation data of The Fabric material obtained in the characterization phase.

tion, and vision coming from the course methodology, together with characterization in the laboratory of fundamental properties and the development of manufacturing tests are consolidating the DIY-Materials development.

With this project, it was possible to see the whole picture, validating how every time a designer follows the different steps and adds a new one, a mature result is achieved. In this case, the possibility to manufacture the material. In the various case studies of **chapter four**, different designers were driven by the manufacturing techniques in preference to the material development. With this work, the aim was to gather the necessary information to justify this relationship between the material development and the making of things which is something closer to the design field compared with the materials science.

For further information regarding the project and deeper analysis on the explored topics refer to (Maino, 2017).

8.4.3. The Fluff Project

Thesis Setting: this research also evolved from the project Fluff **(See appendix 02)**, which is a material created by drying clothes in a dryer. It is the second of the two works in this chapter developing the same topic but producing different incremental steps **(IS)**. For this project, the designer was asked to perform an investigation into the possibilities to give an identity to a DIY-Material.

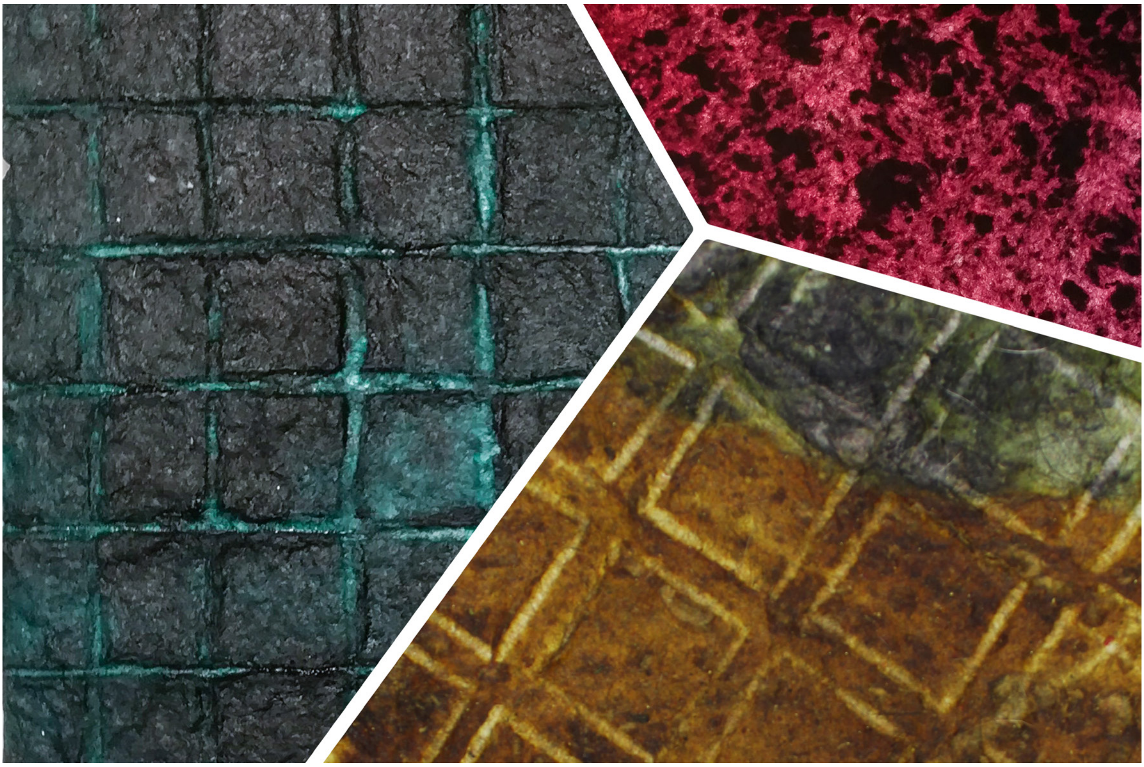


Figure 8.18
The Fluff Material Board.

Background

Knowing that the first thesis work and the parallel thesis of The Fabric Project focus on technical properties, it was the perfect occasion to concentrate on what designers enjoy the most when it comes to materials development. Colours, Materials, and Finishes (CMF) is one of the emerging specializations of the design field. Rooted in the work of Clino Castelli for Herman Miller in the eighties **(See chapter three)**,

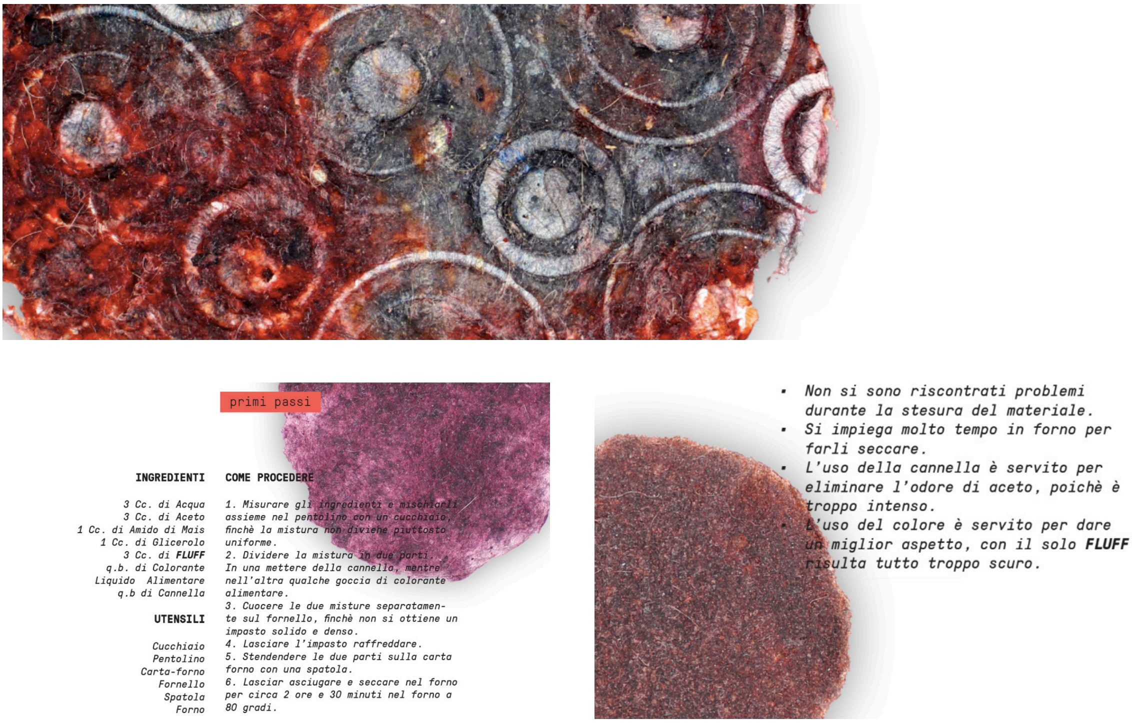


Figure 8.19
Development of The Fluff Project.

nowadays, CMF represents an essential place in the development of products. Textile and fashion industries together with automotive sports apparel and consumer electronics and product companies are hiring designers with the capabilities to understand the expressive-sensorial and experiential qualities of materials to apply them correctly and meaningfully in their products. The DIY-Materials phenomenon can provide alternative aesthetics and languages to products of the future and is balancing the aesthetic cannons the industrial revolution and modernity are imposing (Ayala-Garcia, 2014). This project, aimed to explore with the designer, the possibilities to develop materials analysing trends, fashion styles, and consumer behaviours to create a whole palette of samples (Figure 8.19).

The project made some research on similar trends around the use of related materials. Some artists and fashion designers have presented conceptual work made out of leftovers of the drying machine, a source of matter known as lint (Figure 8.20). The designer Shelly Simcha (a), a designer from Israel, created a piece of garment patching together different pieces made out of this material. Nick Cave, a performance artist from Chicago, is known for his work of wearable fabrics called

Soundsuits (b). One of this piece is made out of lint. Tonya Corkey, a Canadian artist, creates a series of portraits using lint from different colours and tones (c). The Japanese designer Rei Kawakubo presented during the Paris fashion week of 2017, a collection of clothes “wrapping the models in the fabric that forms when you haven’t cleaned out the lint filter in your clothes dryer and sculpt it so that you’re both comfortable and bulbous” (d).

This small trend research showed how contemporary and updated this project was. Although all works found are conceptual and do not express any intention of material development per se, it confirms the chance that this project has to address the topic and create a valuable contribution to the field.

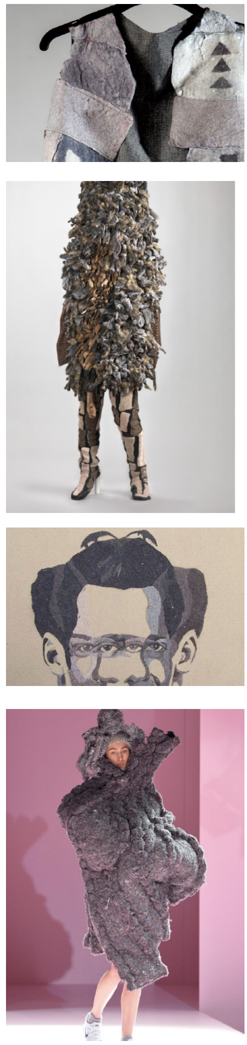


Figure 8.20
(a-d)Trend research of projects made with similar materials.

Developing the collection

The designer took the recipe of the previous project (which was running parallel) and by adding dyes and textures, produced twenty samples. The samples were designed to be part of a sample case, which was tested for qualitative experimentation with a group of users of different ages and cultural background. The result became a series of given attributes perceived by the users confirmed through a multi subjective evaluation process. According to Karana (2009, p. 195) materials obtain their meanings when people distinguish materials in everyday experiences not only by technical functions but also according to what materials mean to them. When testing a material like fluff, which cannot yet be seen embedded in a product, the meaning depends on how the different samples are designed and which senses interact with them. Recognition of smells, visual patterns, and tactile surfaces allow users to evoke feelings and remembrances. With these sensorial stimuli, it is possible to answer the questionnaires and obtain a shared meaning through repeating attributes found in the answers to the surveys.

Sensorial Scales

From the user studies, it was possible to conclude that the material is perceived as friendly, modern, exclusive, crafted, honest and sensible by the majority of the participants of the survey. See the table (Figure 8.21). Some other attributes were perceived in between their contrasting couples, which means, depending on the cultural background of the participant the perception could tend to one side or the other of the scale. This result is not negative at all. On the contrary, it shows

ATLANTE DEL FLUFF
caratterizzazione percettiva

FORMALE

Formale agg. Con accezione limitativa, che si preoccupa esclusivamente o soprattutto della forma, dell'esteriorità, dell'apparenza, e non nasce da una reale e profonda esigenza o trascura i valori intrinseci e sostanziali: una cortesia puramente f.; un saluto, un complimento f.; una persona moto f.; un'educazione rigida e formale.

INFORMALE

Informale agg. Non ufficiale; detto soprattutto (per diretta influenza dell'analogo uso inglese), nel linguaggio diplomatico e giornalistico, di conversazioni o colloquî a carattere privato, e perciò non impegnativi e compromettenti, che si tengono in ambienti o durante incontri ufficiali, a titolo di orientamento senza verbalizzazione. In senso generico, una riunione i., un incontro, un colloquio i., a carattere non ufficiale, privi di formalità burocratiche; per estens., semplice, amichevole, alla buona, riferito a rapporti tra persone (mi ha ricevuto, ha conversato con me in modo del tutto i.), o comune, di tutti i giorni, riferito all'abbigliamento (è venuto alla festa con un abito molto informale).

Figure 8.21
Sensorial scales developed for The Fluff Project.

that the material can embed both attributes depending on the application and perhaps also in the particular context of use. Different results are seen with the other attributes where the majority of participants barely recognize those material qualities and therefore they don't mean anything for this type of material.

Open Questions

From four open questions carefully elaborated to complement the sensorial scales evaluation, it was possible to obtain different attributes that were not perceived before.

- *The first question asks:* What type of emotions, memories or feelings this material evokes?
Many of the answers highlight attributes present on the scales, but some others present new attributes such as familiar and recyclable. Important to highlight from the different answers to this question, the repeated comparison with leather. This recurrent suggestion became a crucial element for the identity definition of the new material.

-The second question asks: Do you think the material is natural or artificial and why?
From the different answers, it was possible to understand how difficult this question was. On one hand, many participants perceived the material as artificial by its colours, textures, and glossiness (designed attributes), but other participants highlighted the elevated level of imperfections inside the different samples concluding that the material was perceived as natural. Again, here it is possible to understand how the material can take both attributes and exploit them differently in the different potential applications.

-The third question asks: What type of elements do you think are inside this material?
The different answers had in common a certainty that the material was a mix of tiny particles of various elements. None of the participants could accurately guess the components inside the material. However, it was interesting to see that regardless of the different configurations, colorations, and textures, the core base of the material expresses itself and highlights its DNA.

-The fourth question asks: Do you like the material and why?
For this last question, the idea was to reveal the material origin at the end to half of the group. For those who knew about the origin of the material, the perception revealed some doubt. For the other half the perception was most of the time positive. Once they understood the source of the material, they didn't change the attitude towards it; some added a surprising emotion while the others remain confident.

This set of questions, together with the sensorial scales, became relevant tools to define the identity of the material. In the materials developed during the third study, there was space to do some user tests, mainly following the guidelines of the MDD method. However, as the material was not mature enough, the different answers at that point could only be useful to define a possible material vision. In this thesis work, it became clear that when doing this type of user studies once the material reaches a more mature and advanced stage of the development, it is possible to establish an identity and purpose a language to capitalize on the future applications.

Expressive-sensorial development (IS-3)

As part of the whole identity development, the student was asked to develop an expressive sensorial atlas for the material. As mentioned in **chapter two**, the Expressive-Sensorial Atlas developed by Rognoli (Rognoli & Levi, 2005 p.121) is an instrument born to support the designer in the selection of the right material, managing the different perceptive and sensorial qualities of them. This tool aims to provide more awareness to the designer who will work with the material, about the different sensorial properties so he or she can enhance them in a further application.

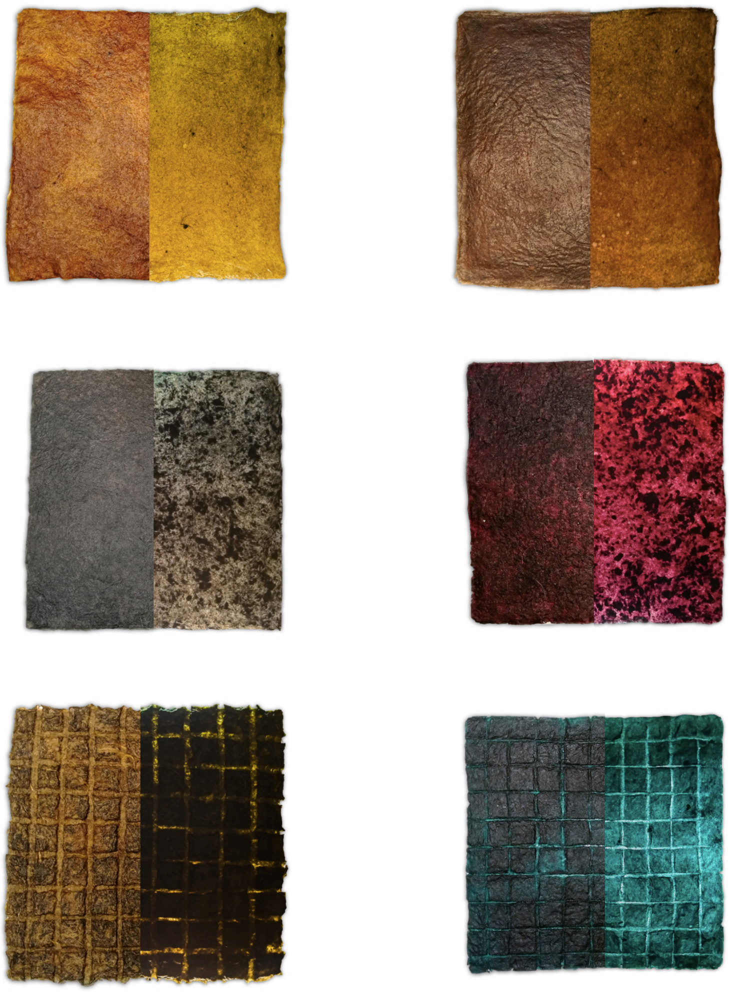


Figure 8.22
Different samples developed for the CMF sensorial Atlas of Fluff.

Figure 8.23
The Atlas of Fluff to develop expressive-sensorial characterization of the material.

The Expressive-Sensorial atlas works with the relationship between tactile and photometric parameters with physical properties of the material. Every aspect is composed of sensorial parameters and qualities. The subjective qualities are connected with the objective ones. For this project, the designer produced eight tables with parameters and properties obtained in the user studies. The eight tables compared attributes as follows: (1) Classic/Modern; (2) Old/Young; (3) Nostalgic/Futuristic; (4) Formal/Informal; (5) Decorate/Plain; (6) Delicate/Vigorous; (7) Disposable/Lasting (8) Elegant/Cheap. (Figure 8.23)
The personality of fluff and the different qualities and experiential properties that it may elicit will come from the various arrangements that the designers who will use it, find using this atlas. The twenty samples (Figure 8.22) together with the eight tables which together compose the Atlas of Fluff, were the contribution of this thesis research to the incremental work that consolidates the DIY-materials development.

Sensorial Characterization
Sensorial evaluation was performed by all projects. In this case is visible in figure 8.24.

For further information regarding the project and a more detailed analysis on the explored topics refer to (Munda, 2017).

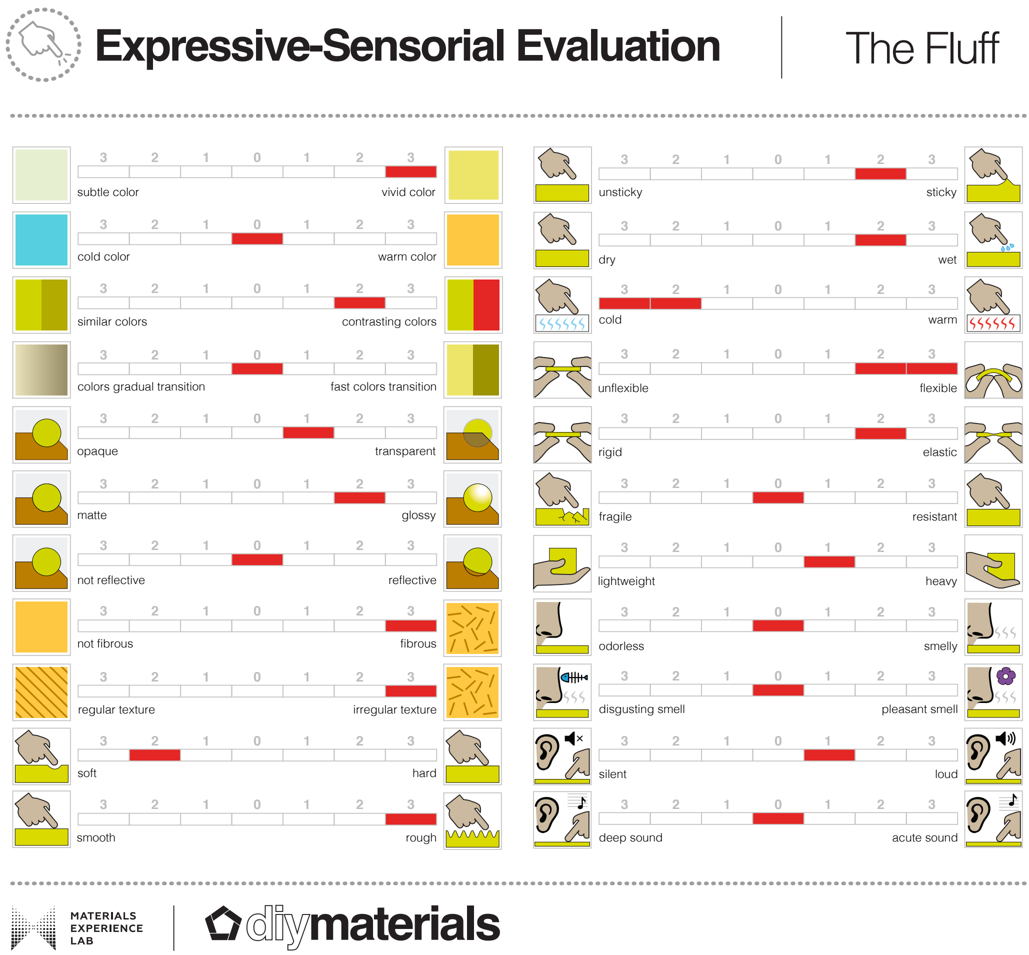


Figure 8.24
Sensorial evaluation data of The Fluff material.

8.4.4. The Pinearex Project

Thesis Setting: DIY-Materials exploring possibilities to tackle Cradle to Cradle principles and Circular Economy Settings. The next step in the development of materials from the design domain will need to go deeper into the places where they can contribute to building alternatives to the linear processes on traditional STEM materials where extraction of resources, upscale manufacturing, and global trade operate. As explained in **chapter three**, the notion of Cradle to Cradle (McDonough & Braungart, 2002), together with the alarms rose through the limits of growth (Meadows et al. 1972) and the rules of the new possible circular economies (Ellen MacArthur Foundation, 2013) will guide the future of the design profession. Materials development then have an opportunity to learn about these practices, and they can be studied and applied to the research methodology of the DIY-Materials development.

Figure 8.25
Pinearex Material Board.

Background

The Ellen Macarthur Foundation as explained in **chapter three** established seven schools of thought that compose the overall concept of circular economy. From Cradle to Cradle, passing by Performance Economy, Biomimicry, Industrial Ecology, Natural Capitalism, Blue Economy to arrive at Regenerative Design. The contributions of this thesis work were to find a material that could be conceived under this framework, moving further from the experimentation process through tinkering to consolidating a material proposal, adding value to the DIY-Materials Incremental Step **(IS)** studies.
The designer explored different possible resources to work, finding a stimulating source: The Pine Nut (Pinus Pinea, described by Linnaeus in 1753), also known as the Italian Stone Pine. The source has strong roots and historical uses in the Mediterranean area, with Italy being one of the big producers of the pine nut, which is considered a highly-valued ingredient in the world of gastronomy and health-related products (Panico, 2017 pp. 60). What is less known is the fact that to extract 5Kg of this precious seed, 100kg of pine cones are collected from the trees, therefore it has a high cost of production. The elevated

amount of production "leftovers" this seed produces represents for the agro-industries who process it, a revenue of no more of the 20% converting it in lignocellulosic biomass (Ogier et al., 1999) used for domestic heating. The Designer contacted one of the big producers of this seed in the Campania region of Italy called Pinoré in the city of Torre del Greco. The company provided the necessary support to develop the thesis work, including the needed amount of material to work. The company also allowed to test the concept of DIY-Material Adoption, an idea to be expanded in **chapter nine**. The opportunity to develop a DIY-Material from the pinecones, a discarded source from the industry that already has an application under the Circular Economy principles used for biomass burning, represented the right opportunity for this part of the study.

The Pinearex Material Development

The first part of the experimentation process is a challenge for the designer as the source (the pine cone), is a hard element to work with and requires heavy machinery to transform. Once it was possible to obtain different grain sizes out of the different parts of the cone, the second challenge was to experiment with building a composite with bio-based resins (Figure 8.26). The information collected from **chapter four** provide information on the type of resins used by different designers in their projects. For instance, the Artichair project from Spyros Kizis, used the Super Sap One bio-resin, which contains a 30% of bio-based carbon content according to the ASTM D6866 test

Figure 8.26
Development of the Pinearex material.

(5.1). Other resins contain bio-based carbon content which oscillates between 30 and 70 percent pairing the mechanical and processing properties of the selected one. For the project, it was essential to use a resin which could be accessible in the southern EU region according to the circular economy principles expressed above. Another bio-resin used during the experimentation process was the Rosin or Colophony, which is also obtained from pine trees and other conifers, abundant in the same geographical region and is 100% biodegradable. The characterization test selected for this material was:

Flexural properties
Following the ASTM D 790, the designer performed a test to obtain information related to the young modulus as seen in figures 8.27 and 8.28 a. Both resins behave, and both composites could work in different types of applications including, for long lasting durable products and for more environmentally friendly short lifespan applications.

Manufacturing test
To shape the different samples, the student was suggested to follow the standard procedures for composite manufacturing which include Manual Lay-Up molding, Spray-Up molding, and machining (Thompson, 2007). (Figure 8.28 b-d).

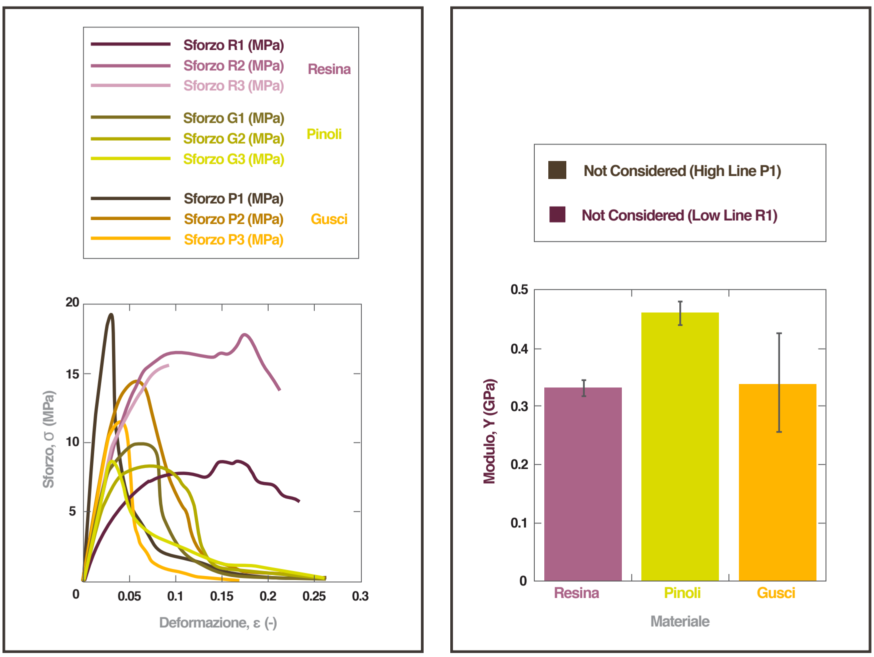


Figure 8.27
Graphic plot of the characterization phase.

Figure 8.28
Pinearex showing all incremental steps from top to bottom:
(a) Characterization of the material.
(b-c-d) Manufacturing tests.
(e-f) CMF development.

Designing material samples
Another contribution to the incremental work that consolidates the DIY-materials development from this thesis was the idea of designing the samples to express its sensorial qualities (Figure 8.28 e-f). Once the student was confident with the manufacturing techniques and the management of both bio-based resins, he began a series of experimentations around which shapes could express the attributes of the material to inspire applications. By doing so, it will be easy to convince the company which supported the project (or other potential stakehold-

ers) to see the possible value of an existing source such as the pinecone shells. Presenting the material to the company together with technical data obtained as an initial characterization of the material, served to open possibilities for further developments and applications.

Sensorial Characterization
Sensorial evaluation was performed by all projects. In this case is visible in figure 8.30.

Pinearex towards a circular economy material (IS-4)

The material developed through this thesis work was measured with standard tools for life cycle assessment such as the eco-audit tool of the CES Edupack from Granta (Figure 8.29). The simulation reveals a high potential concerning embedded energy, reduction of carbon footprint and zero waste through upcycling of residues compared with standard composites made out of similar grain reinforcements such as Particleboard, Chipboard or Medium Density Fiberboards. (compression of particles and jet sprayed resin are not considered as those are engineering manufacturing techniques that may be applied in future steps). The simulation showed how, if the material is used in the same area for similar applications, the ecological impact and the co footprint decreases substantially. This hypothesis could be demonstrated with more in-depth characterization and prototyping the suggested application with the material. However, we aim to illustrate the possible path towards a circular economy approach, when DIY-Materials are considered, developed following the method presented in this thesis and presented to potential stakeholders.

Different from its hypothetical competitors (particleboards), the designer explored ways to express its identity by enhancing the surface texture. Unlike from particleboards covered with a layer emulating another material, colour or finish, this material through its expressive-sensorial qualities could become more appealing to users in the similar applications. All this if the material manufacturing and distribution remains in the local context where the pinecone grows.

Figure 8.29
Life cycle simulation of the Pinearex material.

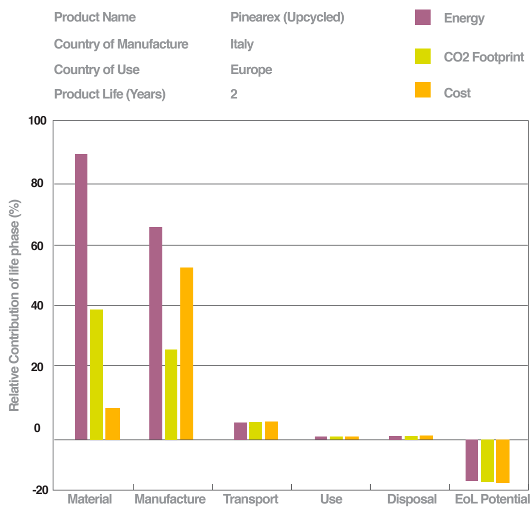


Figure 8.30
Sensorial evaluation data of The Pinearex Material.

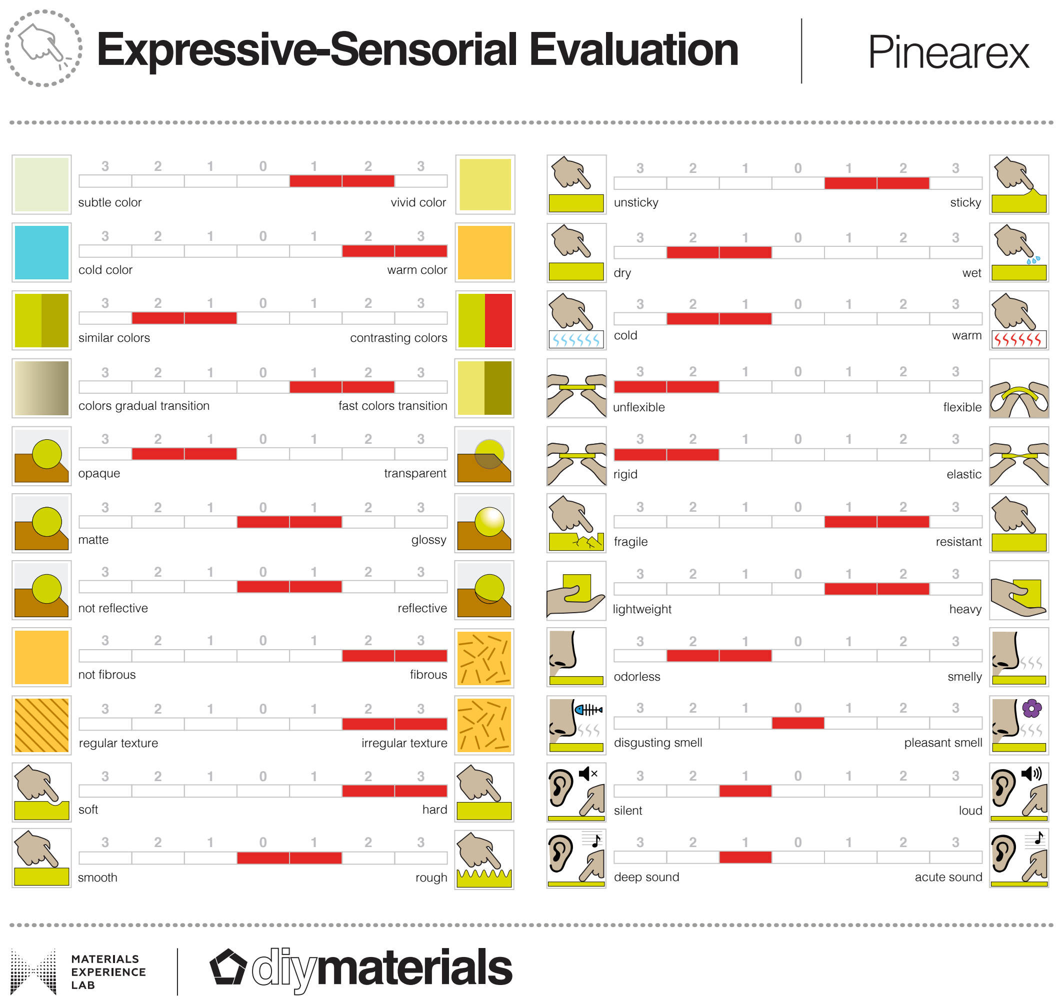


Figure 8.31
DIY-Cornstalk Material Board.

For further information regarding the project and detailed analysis on the explored topics refer to (Panico, 2017).

8.4.5. The DIY-Cornstalk Project

Thesis Setting: DIY-Materials exploring possibilities to address circular economies through social innovation practices. This thesis project compared with the previous projects had an input which could be exploited to test out theories outside the design domain. The student was not a designer. Mrs. Rodriguez was trained as a management engineer and enrolled in the master of science in design engineering which is open to both engineering and design related disciplines. Under this context, it was clear that not being trained as a designer she will need additional information and training to perform all the previous steps defined in **chapter seven**. Everything used as a theoretical stimulus, together with the findings of the previous thesis works, was organized in a series of sheets and given to the student as an introduction to design methodology in seven personalized sessions in the same order as delivered to participants in the previous study. As explained in **chapter three**, one of the critical elements to achieve social innovation from the design perspective comes when the design expert supports the capability of other actors to design in a dialogic way. It can guide and provide the tools to interact with the other actors in order to achieve the desired goals and empower the other to act and find the solutions by themselves (Manzini, 2015 p. 67). In this case, the researchers acted as design experts and the students became the receptor and user of the information to transform collectively. It was a test of knowledge transfer made on purpose to analyze the different critical points this approach may have. If the results are positive, as they effectively were, the same methodology could serve to transfer knowledge within the project to other actors, specifically the farmers and their communities.

Background

The third macro area of research explained in **chapter three** is related to the different theories and knowledge around social innovation from the different disciplines who work in this field, starting from sociology (Howaldt, 2008) through business and economics (Nicholls, 2006) and recently, design (Manzini & Meroni, 2014). The interlaces, and interconnections of the three macro areas and their particularities are the focus, as is in this interconnection and relationships where the Do-It-Yourself-Materials phenomenon can be better understood. Therefore, to conclude the study it was crucial to approach the topic of social innovation with a materials development work, not only as a validation of hypothesis but to find opportunities for the DIY-Materials theory beyond the design domain.

The designer was encouraged to find a material of interest like all the others participants of this study. The only additional element to the brief was to search for material sources which can in one way or another contribute to one or more pillars of sustainable development: the people, the profit, and planet (Elkington, 1994).
Through her research, she ends up analyzing corn, which is a very resilient crop cultivated in the world, particularly in Colombia, where it has a high nutritional and economic importance for many families. Targeting this crop will increase the potential impact of this research towards a sustainable solution. Corn grains have multiple uses and contain a high nutritional value. Regarding crops management, between 70 to 80 percent of the nitrogen contained in corn is embedded in the grains. Conversely, Cornstalk has a low nitrogen content and a

high carbon/nitrogen ratio which makes it hard to decompose under natural circumstances. Studies revealed the impact of not leaving corn stalk in the fields to disintegrate, and the results show that: "even though cob residues did slightly delay the start of runoff, they do not affect rates of sediment loss" (USDA, 2013). Therefore, removing them for a second life will not alter the role of residues as soil protectors. Corn production is such an old and common practice that it is possible to trace some of the uses of corn stalk for centuries. Currently, there are multiple types of research investigating potential uses. These leftovers could not become waste but instead, an input that can be upcycled through several uses before continuing its natural decay and decomposition.

Corn Stalk Material Development

Corn stalk, being one of the most accessible elements in different regions of Colombia, was the right choice for DIY-Material experimentation. Hence, this practical experimentation will promote social innovation by redefining corn stalk as a possible resource to exploit by a rural community becoming an enabling agent to meet their social needs and enhance their capacity to improve rural living standards.

For many years, corn has been the most cultivated grain in Colombia. Although it is global importance has increased, in the last years, the area dedicated to its cultivation is decreasing as a result of economic aperture policies which profoundly affected the agriculture sector through free imports with reduced taxes and low international trade prices. Recently, the free trade agreement between Colombia and the United States which started in 2012 has made the local production even harder. The local farmers must now compete with the prices of mass produced corn that has a tax exemption for twelve years (Delgado, 2015).

In Colombia 85% of the internal production is carried out by small producers in areas smaller than five hectares. Around 200,000 families depend on this occupation and they do it according to the traditional method (SIC, 2012). These conventional methods rely on the use of seeds obtained from the harvest, without the use of chemicals. Production is predominantly carried out on small scales and has an average yield of 1.5 Ton/Hectare. In contrast, the technology heavy method uses improved seeds, fertilizers, pesticides and expensive machinery to increase crop yields up to 4.5 Ton/Hectare. Consid-

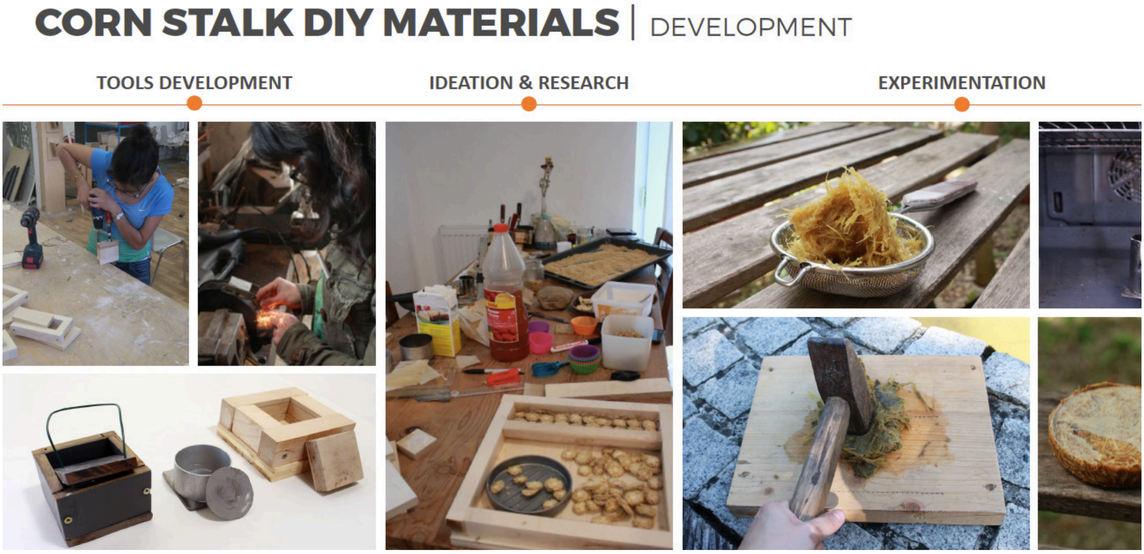


Figure 8.32
Development of the Cornstalk DIY-Material.

ering that technology improvements to harvest are more productive concerning crop yield, the government has fostered the transition and encouraged the increment in the planted area to reduce the dependency on imported corn through credits, subsidies on supplies, technical assistance and alliances with producer's associations (Minagricultura, 2016). However, fertilizers which represent 50% of the production cost, together with most seeds and agrochemicals used in the technical production are also imported or somehow also depend on the Dollar value.
In comparison to imported corn, the national corn is still more expensive. This higher price does not necessarily translate into higher revenue. 37% of the population in the rural area (more than 5 million people) whose primary activity is related to agriculture live in multidimensional poverty, which regards poor health, education, and low quality of life standards (Op. cit., 2015). Finally, depending on the currency devaluation in respect to the dollar and the oil prices, it is sometimes even more expensive for them to harvest and transport their crop than to let it rot in the fields.

With all this information as background, the potential and opportunities such material source was clear to the designer. Achieving a positive result could be the first step towards sustainable development through DIY-Materials.
The designer began a series of experimentations with corn stalks and corn leaves testing different combinations and percentages (Fig-

ure 8.32). The other ingredients added to the experimentation and tinkering phases were chosen considering the accessibility, price and environmental impact to have a reasonable outcome aligned with the targeted social, economic and cultural context. For instance, a suitable binder was one of the hardest things to achieve. In many of the research studies and examples, even in the previous thesis work explained above, the use of resins to bind the material is a standard but they are hard to find in rural areas, and they could also be expensive. In contrast, the student found the following binders that farmers could easily find:

-Calcium hydroxide: this is a component extracted from limestone, used by farmers as a natural fertilizer or to cook traditional meals.
-Panela: Panela is unrefined cane sugar, typical in Colombia. It is a

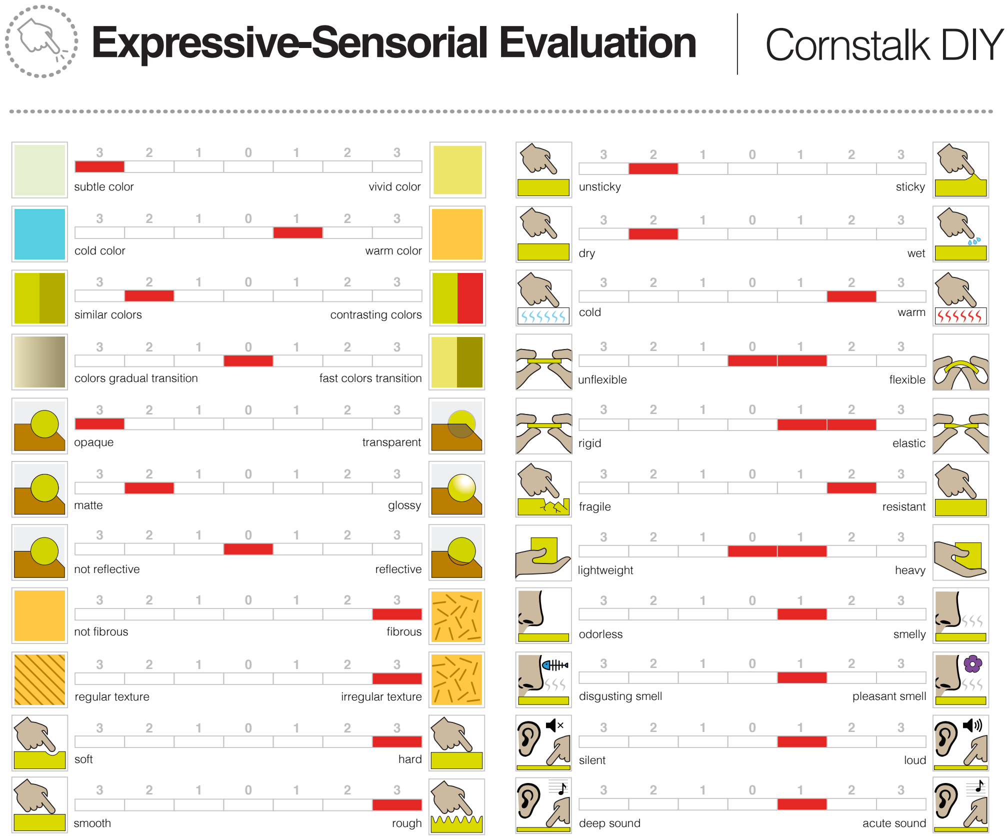
Figure 8.33
Tuning and testing phases of the material.
Above:
(a) Tests with different formulations.
Middle:
(b) Characterization phase.
Below:
(c) Technology transfer and workshop with farmers.

solid form of sucrose derived from the boiling and evaporation of sugarcane juice.
-Corn Starch: Corn starch is a common food ingredient, used in thickening sauces or soups, in making corn syrup and other sugars and recently a principal ingredient in the making of DIY-Biopolymers.
-Linseed Oil: Is a colourless oil obtained from the dried, ripened seeds of the flax plant. Linseed oil is a drying oil, meaning it can polymerize into a solid form.
-Sawdust: It is composed of fine particles of wood. It is a by-product of woodworking operations and is the main component of particleboards.
-Mud: It is a liquid or semi-liquid mixture of water and any combination of different kinds of soil. This material is still used in a variety of ways to build walls, floors and even roofs in Colombia.

For each experiment in this project, factors such as cost, ingredient accessibility, and processing energy were analysed. The last factor is of extreme relevance, as in the remote rural areas there is still a high percentage of the population without access to electricity. At the end of this process, 50 experiments were carried out (Figure 8.33 a). Each one was characterized regarding their sensorial qualities, the context variables and a brief description of the followed process.

Sensorial Evaluation

In the previous thesis of fluff, it was possible to see that an expressive sensorial atlas is an instrument which could support the designer in the selection of the right material, managing the different perceptive and sensorial qualities of them. With such a broad number of materials samples, this could be a right thing to do. However, as the project had a more complex focus and limited time, this step was skipped on purpose allowing the student to perform a sensorial evaluation in the same way it was made in the course of the third study. The different sensorial qualities of the various experiments and samples were subjectively evaluated making use of the categories and scales (Figure 8.34). Two of them- reflectiveness and weight - were not used, as none of the obtained materials is reflective and the weight is relative to the number of ingredients used in each sample.



Forming and processing Corn Stalk

To shape the different samples, it was recommended to the student to follow the standard procedures for composite manufacturing as well which include Manual Lay-Up molding, Spray-Up molding, and machining (Thompson, 2007). During this phase, the machinability and processability of corn cob and different corn stalk DIY-Materials samples was evaluated using universal machines such as a band saw, a drill and circular sander. The outcome was that all the material samples could be processed using these tools similarly to wood-like materials. With this input in mind, the student reaches the wood technology program of the Salzburg University of Applied Sciences, to perform different tests typically made to characterize fibrous materials (Figure 8.33 b).

Figure 8.34
Sensorial evaluation data of DIY-Cornstalk material obtained in the characterization phase.

Characterization of CornStalk DIY-Material

Four materials out of the fifty were perceived to be strong enough to perform the characterization tests by the sensorial evaluation and the forming procedures. Density was measured through the (EN 323)

(Figure 8.35 a). The following two tests, three-point flexural strength (Figure 8.35 b), and transverse tensile strength (Figure 8.35 c) are typically made to characterize fibrous materials. The last one, the thermal conductivity test was applied to one of the samples to determine if corn stalk-based materials can also perform as thermal insulants (Figure 8.36 d).

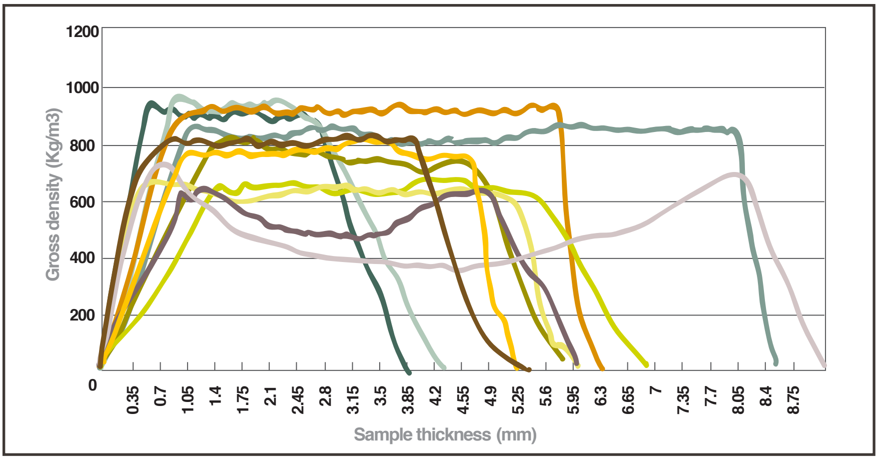
Flexural Strength
Determination of modulus of elasticity in bending and bending strength for wood-based panels according to the EN 310. This specifies a method of determining the apparent modulus of elasticity in flatwise wood-based panels of a nominal thickness of 3mm.

Transverse Tensile Strength
Determination of tensile strength perpendicular to the plane of the board of particleboards and fiberboards according to the EN 319. This standard is applicable to Oriented Strand Board primarily but it can be used for this samples as well. It specifies a method for determining the resistance to tension perpendicular to the plane of the board (internal-bond) of particle boards. For this test, it was important to assure the distribution of the particles inside the material sample.

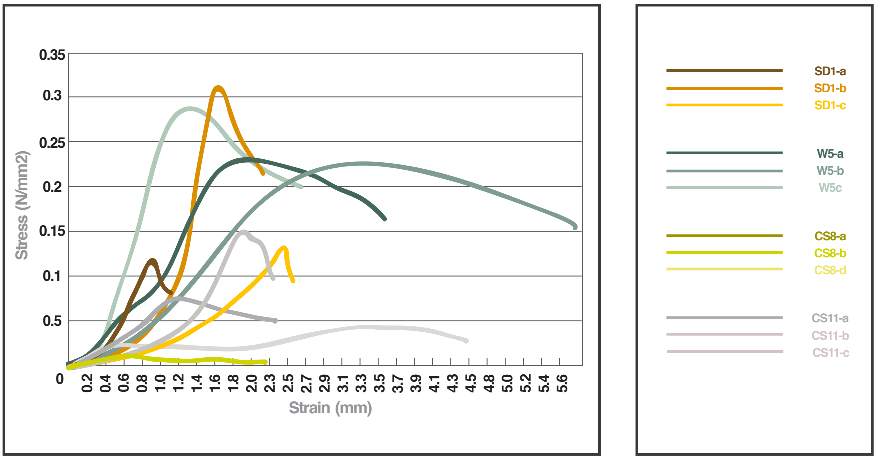
Thermal Conductivity
(EN 1946-2) Accurate measurement of thermal conductivity is possible through the use of guarded hot-plates and heat-flow meters. These instruments create a steady-state temperature gradient across the material sample. The amount of power required for the heated-plate to create a particular temperature gradient will be proportional to the thermal conductivity of the material.

Tests Outcomes
From the tests conducted and the sensorial evaluation, it is apparent that Cornstalk DIY-Material density is between the ranges of equivalence of Medium Density Fiberboards (MDF) boards.
- It behaves similarly to Compact Density Fiberboards (CDF) and plasterboards regarding tensile strength.
- When it comes to bending strength, it places beneath chipboards but some adjustments in terms of thickness accuracy for tests still need to be improved.
- It shows a thermal conductivity behavior similar to Medium Density

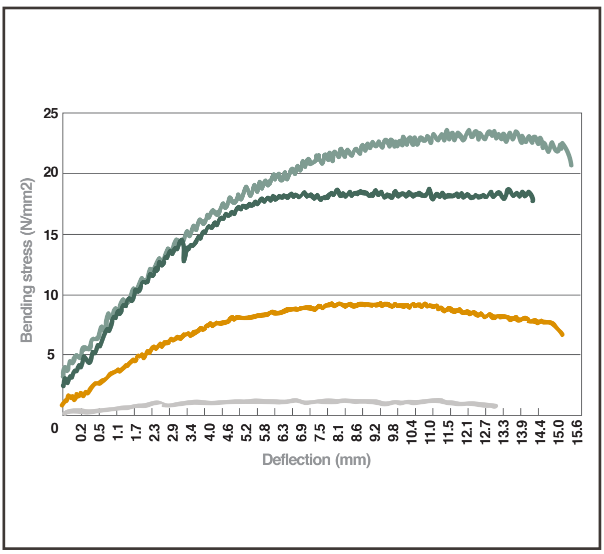
Figure 8.35
On the next page.
Graphic plot and charts of the characterization phase.
Above:
(a) Density test.
Middle:
(b) Flexural strength test.
Below:
(c)Transversal tensile strength test.



Density (EN 323)		
Sample	**Gross density (Kg/m3)**	
SD1-a	641.5	697
SD1-b	797.3	
SD1-c	651.7	
W5-a	700.2	701
W5-b	757.4	
W5-c	644.6	
CS8-a	602.0	563
CS8-b	519.4	
CS8-d	568.0	
CS11-a	474.0	474
CS11-b	477.0	
CS11-c	470.6	
Benchmark	**(Kg/m3)**	
CDF Board	1000	
MDF Board	840-890	



Transverse Tensile Strenght (EN 319)	
Sample	**Transverse tensile strenght (N/mm2)**
SD1-b	0.300
W5-c	0.283
CS8-d	0.006
CS11-b	0.145
Benchmark	**(N/mm2)**
CDF Board	2
MDF Board	0.65
Chipboard	0.8
Plasterboard	0.3



Flexural Strenght (EN 310)			
Sample	**Flexural modulus EB (N/mm2)**	**Bending stress BB (N/mm2)**	**Thickness (mm)**
SD1-a	457.4	9.2	3.7
W5-a	1051.7	18.8	1.9
W5-b	1703.4	23.7	1.8
CS11-a	-	1.2	8.7
Benchmark	**Flexural modulus EB (N/mm2)**	**Bending stress BB (N/mm2)**	**Thickness (mm)**
CDF Board	6000	60	11.8
MDF Board	2700	23	4
Chipboard	4500-3200	25-18	13
Plasterboard	2000	2.2	9.5

Thermal Conductivity (EN 1946-2)	
Temperature	**λ (W / mK)**
10 °C	0.09
25 °C	0.10
40 °C	0.11
Benchmark	**λ (W / mK)**
Plasterboard	0.32
MDF Board	0.15
XPS Board	0.029

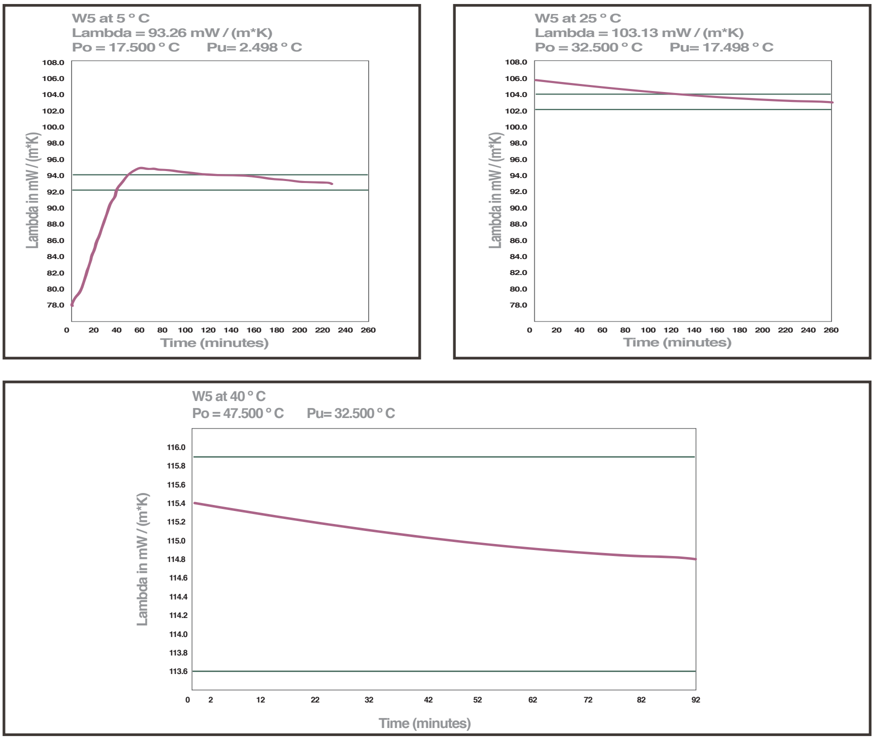


Figure 8.36
Graphic plot and charts of the characterization phase. (d) Thermal conductivity.

Fiberboards, at some moderate temperature ranges.

Like all the previous projects, more in-depth characterization is required to achieve a robust comparison and to be able to suggest possible applications in the future. However, the tests aimed to provide quantitative and qualitative support for the project and to give a better understanding of the corn stalk material to present to the farmers and their community. The sensorial tests revealed the potential of the material to be perceived as something useful and aesthetically pleasant. Considering the previous statements, it is possible to say that the transformation of corn stalk through the DIY-Materials methodology opens up alternatives for potential uses in places where access to benchmark materials with similar grain reinforcements such as Particleboard, Chipboard or Medium Density Fiberboards is relatively difficult. Further tools and process refinement could make these materials competitive or substitutes for standard construction and furniture materials. Also, farmers and their community could find new applications to satisfy their material needs or opportunities present in their context. Hence, giving place for the development of a social business which could be wholly carried out locally involving raw material producers, creators, manufacturers, and distributors.

CornStalk towards a social innovation (IS-5)

Once proved how to develop DIY-Materials taking into account the constraints that farmers might face, the next step will be to evaluate the social feasibility. In other words, the next step is to assess whether or not the proposed topics could spark the interest of the farmers and if the principles followed were true to the farmers' reality. During this process, the theoretical research provides tools for planning some workshops following a peer to peer conversation. In these workshops, it was key to include farmers' empirical knowledge and experience as valuable capabilities to develop DIY-Materials. All pluralistic and democratic characteristics of DIY-Materials such as the use of local resources, practical experimentation and the creation of personalized tools and methods, were used to perform the workshops. All of these factors combined make farmers understand that this could be a business alternative where they do not have to face the traditional resources acquisition, knowledge and technology barriers. Tools such as videos, images, tangible examples, questionnaires and personal experiences were added to each workshop to provide the better possible picture of the advantages that these types of developments could represent to the community. Five workshops in three different Colombian rural areas were carried out, with a total of fourteen people from different ages and backgrounds involved.

For the hypothesis ascertainment through the workshop, it was necessary that the farmers understand what DIY-Materials are, what is the aim of this type of approach, how to produce them and why a community strategy around the topic brings advantages for all. By presenting tangible examples of some of the corn stalk-based DIY-Materials made, product examples, speaking from first-hand experience of the student and openly discussing processes, ingredients, and tools used, farmers realized the potential and capabilities they have to develop materials themselves. They also recognized the advantages and the wide variety of uses and applications these

Figure 8.37
Workshop with corn farmers in Colombia.

kinds of materials could have. Furthermore, they identified it as a business opportunity to create economic profit and create local employment with relatives and neighbours who have other skills like carpentry or manufacturing crafted goods or even populate local diners and cafeterias, schools and parks with furniture made out of these materials (Figures 8.33 c and 8.37).
From a community point of view on which social business is based upon, it is possible to say that even though the social interaction between farmers and their communities were different, all the farmers had a very positive attitude towards sharing ideas and working together with other people. While developing small-scale agriculture, most of the farmers had already experienced how they could help each other to farm, harvest, share knowledge and enrich their social life. Therefore, they see the work with others not only as a strength but also as something they would intuitively do to help each other. Furthermore, at an entrepreneurial level, it was clear for them that more people mean more resources, ideas, and skills which would enable them going beyond covering individual needs to starting a small business. "If you would be able to make a small company you could look for other people and other sources of waste," said Leonidas Bernal, a local farmer who attended one of the workshops.

Corn stalk based materials may be similar according to some performed tests to Pinearex from the previous thesis work, but it will be made and used in another context. This statement is the root of the materials generation for circular economies and for social change. Throughout this thesis work, it became visible how it is possible to imagine a world where the global supply of materials forcing standardization and mass production won't suit for all. Specially where local resources could perform in a similar way as foreign materials for some intended solutions providing economic opportunities to different actors inside a community.

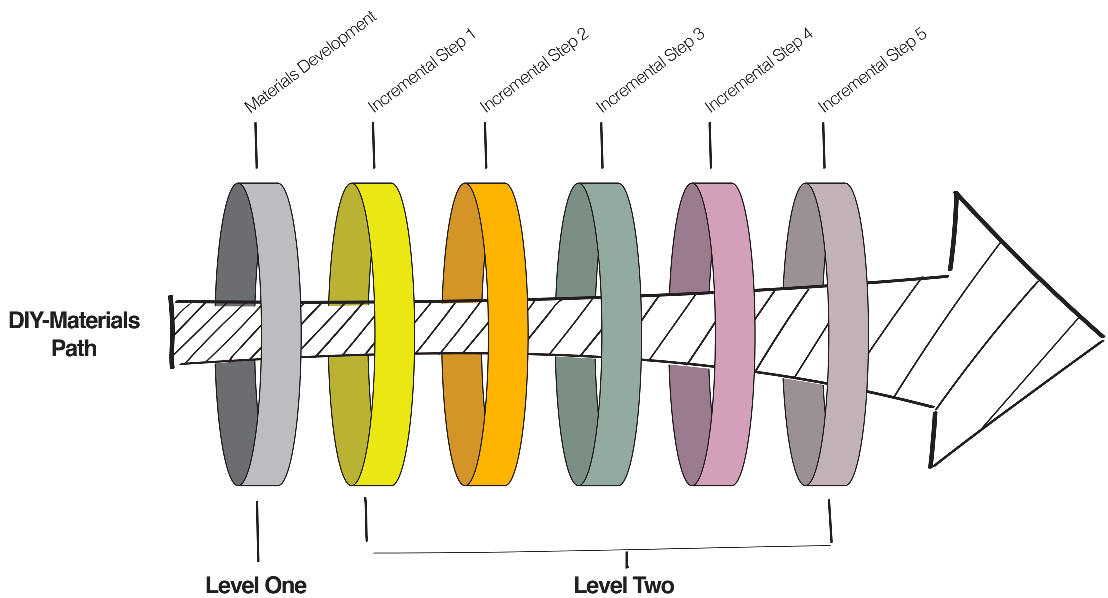
For further information regarding the project and a more detailed analysis on the explored topics refer to (Rodriguez, 2017).

8.5. Outcomes

The five incremental topics developed by the participants of this study through their thesis work showed how it was possible to take the DIY-Materials development further. Each project added significant incremental step into the whole development pathway. Although not all projects had the same duration and expected results, each one committed to the structure and delivered the incremental steps contribution to the general DIY-Materials study. In (Figure 8.38), it is possible to see the recapitulation of the different incremental steps connected with the outcomes of the previous study.

As is explained in the different chapters, the studies within this research are not linear but iterative. In this particular study, it is important to highlight that the incremental steps explored by each project could be embedded into the other projects, but only if the development requires it. In other words, the study aims to obtain a deeper look into the DIY-Materials development and a series of steps were proposed and developed. However, not all projects needed to adopt a particular incremental step **(IS)** as depending on the project, one step

Figure 8.38
Incremental steps of the DIY-Materials development.



could be more important than other. The different steps contribute to a better understanding of the DIY-Materials development pathway but they are not necessarily meant to be followed in a certain order.

8.6. Findings and validation of hypotheses

The study produced mature and consolidated materials proposals. All the participants followed the given tasks accordingly to the structure of the study and arrived at a material sample highlighting an incremental step **(IS)** as part of the whole development of the project. The fourth test hypothesis **(TH4)** which suggested that *DIY-Materials can achieve a mature level of qualitative development and it is possible to analyse them with standard methods to reveal qualitative data* was satisfactorily tested. Each project performed a series of tests by following standard methods required to withdraw properties and understand possible performance (only one project did not include this requirement based on the incremental step focus). The study demonstrates the ability designers have to approach a project from different perspectives to achieve the requested results. In the study of **chapter seven**, all participants remained in a controlled environment were craft tools, design methodologies and tools were used to achieve some particular results. In this study, the designers move outside this controlled zone to interact with scientists, engineers and sociologists to systematically achieve the proposed goals. Apart from the specific aims and findings of each material development, each project contributed collectively to the study of this research. The different incremental steps became crucial and connected properly with the results of the previous studies.
The first project demonstrates the capability to perform a series of characterization tests to withdraw initial physical properties of a material. Persuading materials scientists to believe in the DIY-Material sample highlighting experiential qualities of the material is fundamental to start this type of laboratory tests.
The second project demonstrates the capability to transform the material into a particular shape. The use of DIY tools is part of the ability to craft and these manufacturing principles can be afterwards tune-up by engineers either by a known manufacturing process or developing a new one proposed by the designer.
The third project demonstrates the capability to develop a material identity by exploring different compositions adding surface treatments, colours and the development of different textures. The development of sensorial qualities of a material become an important role

in the materials development and is a place where designers could have a broader place to work.
The fourth project demonstrates how a DIY-Material development can trigger circular economy practices by researching sources, experimenting and proposing a whole cycle of development and lifespan of a material. Finding the resource, developing it and addressing a company for further possible developments is one of the possible streams that a DIY-Material can follow.
The fifth project demonstrate how a DIY-Material development can trigger social innovation practices by researching sources, experimenting and prototyping within a community where the material resource is available. This stream is probably where DIY-Materials could find the more meaningful applications addressing solutions for different issues where traditional STEM materials have difficulties to interact.

8.7. Conclusions

The fourth study showed, that when designers deepen into the material development, they can achieve advanced levels of understanding and manipulating some properties and qualities of the material. From this study, it is also possible to conclude how DIY-Materials can be developed with different stakeholders encountering possible streams for application either in small-scale production, inside industry or within a particular community.

The study also revealed how designers could add incremental steps to the development of a material, particularly by addressing different issues and collaborating with different disciplines and stakeholders. Many STEM materials developments follow a standard procedure where research on performance is the main focus. In this research, it became visible how a designer can achieve important results in developing a material by focusing on other aspects (either performative or not). It is essential to find the right tests to perform as well as to involve the different stakeholders who can contribute actively in the development of the project.

The different incremental steps proposed to each participant, improve the materials and enrich the DIY-Materials Theory. Through this study appear visible how when traditional material scientists and designers meet in the development of a material, the samples achieve higher standards. Not only by understanding the physical properties.

Also as the experiential qualities and sensorial attributes of the material become elements to maintain, even when the material needs to be tuned up for manufacturing or is evolving towards a possible application.

Chapter Nine

Outputs

In the previous chapters, there has been an extensive explanation of the DIY-Materials phenomenon. The studies performed to validate proposed hypotheses and answer to the different research questions can be read independently or as a whole, and could spark discussions around the emerging materials experience topic of this doctoral research. In this chapter, the aim is to present the different outputs obtained during the studies in an organized and clear way. Putting all the different outputs in the same place can help designers to understand step by step the various tasks needed to develop a material, adding a new step or modify an existing one. It is not considered a method, but a series of organized insights that could help in the development of a material of any kind.

9.1. Outputs from exploration studies

9.1.1. DIY-Materials Boards

The different materials explored were visually arranged to inspire, not by the application as it is commonly presented on the designer's website, but from the features of the material. Each board is arranged in a layout that allows seeing particular elements and qualities of the material from a visual point of view (Figure 9.1). The material boards comprise the different materials which appear in the DIY-Materials database and are designed to highlight the designer's intentions during the materials developments.

9.1.2. DIY-Materials Database

The whole collection of cases, as well as the different results of the test studies, are being archived in an open source website (www.diymaterials.it) (Figure 9.2). The initiative seeks to disseminate the whole work of the DIY-Materials theory and invite designers, universities and

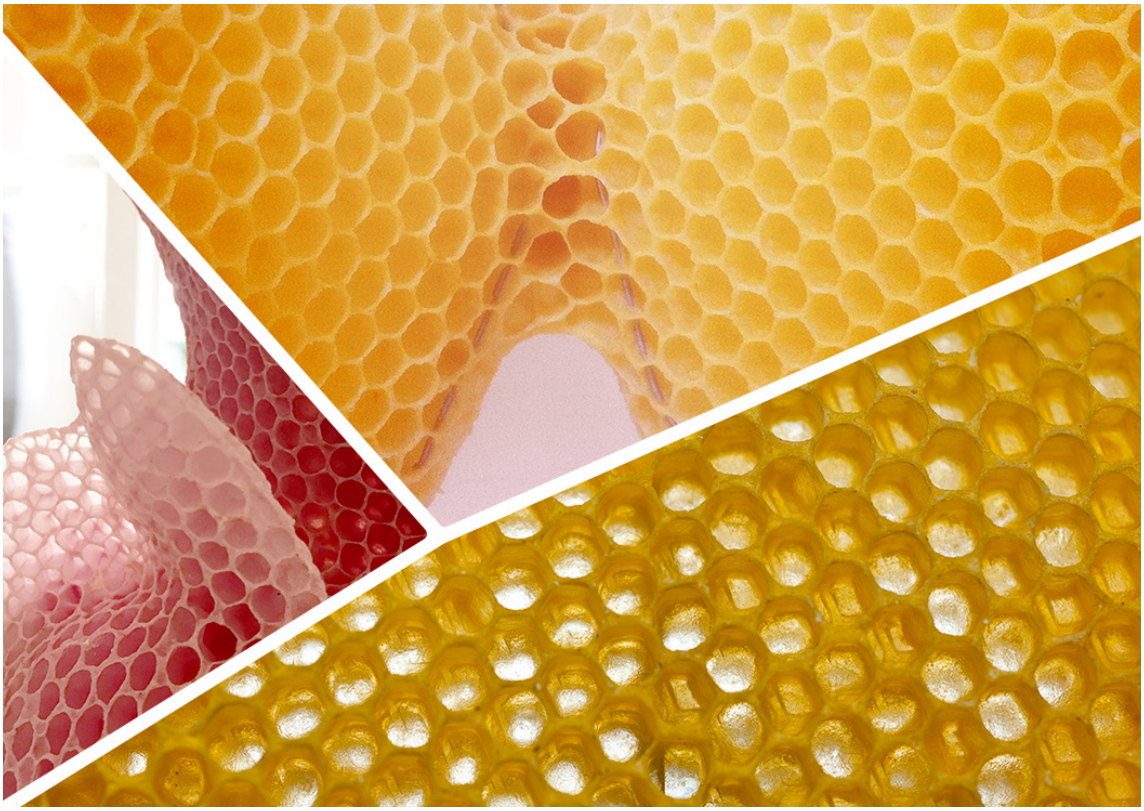


Figure 9.1
DIY-Material Board Made by Bees from Tomáš Libertiny.

other institutions to design materials, share results, improve recipes and upload content. The website is divided into three main parts:

- The DIY-Materials Database: all the different cases explained in chapter four are included in this database. The database is split into kingdoms for easy access to content, and each particular case is described as a result of the evaluation process of chapter five. The credit to the designers as well as their contact is carefully cured in case someone wants to get in touch with the creators of the material (Figure 9.3).

- Instruments to experiment: all the different elements which compose the test studies and the roadmap explained in this chapter are in this section. The aim is to provide as much information as possible to conduct materials experimentation assuring a high standard of quality.

- The materials Club: All material samples created within studies three and four are presented in this section. The idea of a materials club

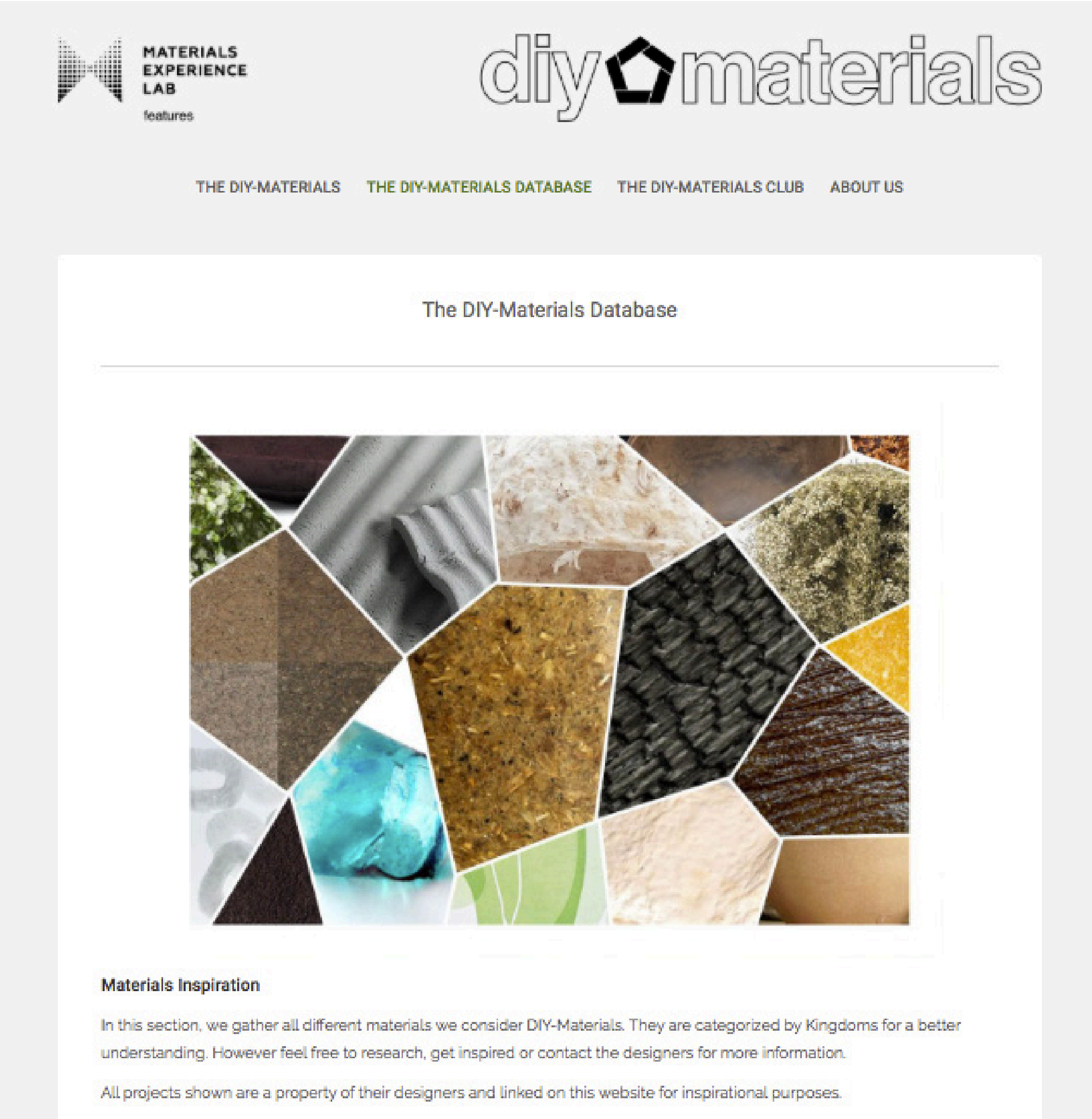


Figure 9.2
Open source website (www.diymaterials.it)

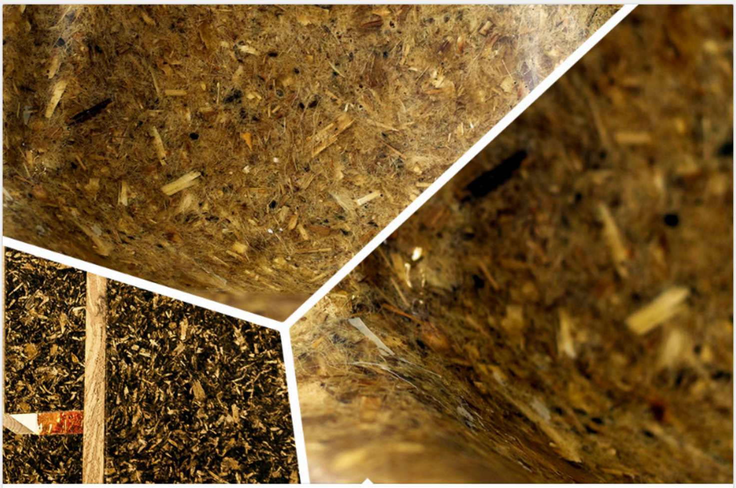
came after the conclusion of both studies and represented an ongoing project that allows creating DIY-Materials using existing laboratories and existing infrastructures either in universities or in the city. A detailed description of the concept of the materials club is available at (Zhou, Z., Rognoli, V., Ayala-Garcia, C. (2018). Educating designers through Materials Club. In: Proceedings of the 4th International Conference on Higher Education Advances (HEAd'18). Valencia, Spain, June 2018 - ISBN:978-84-9048-690-0)

MATERIALS EXPERIENCE LAB

features

diy materials

THE DIY-MATERIALS | THE DIY-MATERIALS DATABASE | THE DIY-MATERIALS CLUB | ABOUT US



Artichair – Kizis Studio – (Greece)

9 October 2018

Kingdom: Vegetabile.

//Description

"The artichoke thistle is an edible plant that has been harvested in central and western Mediterranean regions since ancient times. One of the most prevalent plant species in Greece, the artichoke thistle is well adapted to dry climates and has been identified as a promising natural resource for the local biofuel industry.

Seeking a fresh use for byproducts of the plant, designer Spyros Kizis has developed a biodegradable ecomaterial composed of the plant fibers and bioresin—essentially a plant fiber–reinforced plastic. Kizis has used the material to create compression-molded components for a variety of interior furnishings, including a lounge chair, dining chair, and coffee table.

Because the new composite utilizes plant components that are not employed to make biofuels, the fabrication process may be creatively coupled with biofuel production to take full advantage of the natural resource. Since the furniture is inherently biodegradable, artichoke thistle seeds are intentionally interspersed within the reinforced material during fabrication. Buried pieces can thus germinate new plants." (Brownell, 2016)

Material Qualities

Kingdom Attributes

- Disorganized
- Rough
- Fibrous
- Discontinue Surface Pattern
- Unique
- Irregular
- Non-Uniform Coloration

Specific Material Attributes

- Dirty
- Aggressive
- Extravagant
- Thick
- Coarse
- Saturated
- Packed

Basic Ingredients

- Artichoke thistle Fibres
- Bioresin

Contact

Kizis Studio

+44 7554 727374

spyroskizis@gmail.com

http://kizisstudio.com/

————————————

Images property of the material owners.

-Brownell, B. (2011) Artichair. Retrieved from http://transmaterial.net/artichair/

Figure 9.3
Database detail of each material showcased with the material board.

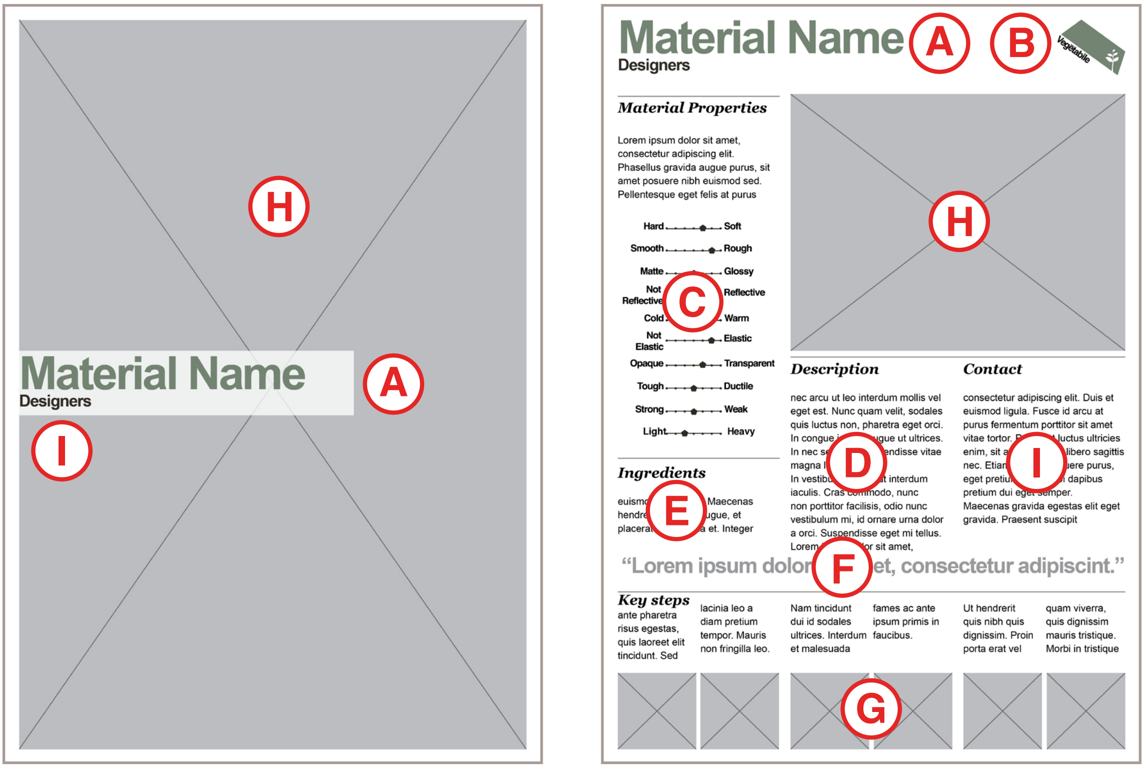


Figure 9.4
Material Datasheets template.

9.2. Outputs from test studies

Together with the material samples, there are a series of elements which compose the DIY-Materials delivery. Everything has been carefully studied and connected with the theoretical stimuli provided during the studies.

9.2.1. DIY-Materials Datasheets

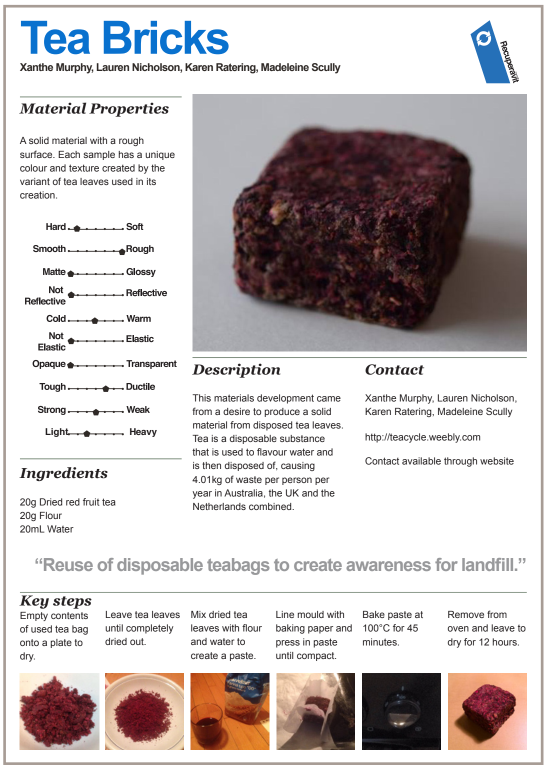
The data sheets were designed to contain all the different information relevant to material development (Figures 9.4-9.7). It consists of various sections designed to provide valuable information about the material, but also to highlight the process behind the DIY-Material. Having such uniformity concerning layout allows to analyse the different materials and evaluate the different outcomes. As explained in chapter five, one of the main features of a DIY-Material development has to do with the driver source, which is the particular aim of the designer to develop a specific material. This driver is a critical element of the story around the material, and it is embedded in the datasheet as well.

A. Material Name

Material science names the materials mainly in three different ways: according to the chemical compound (Ethylene Vinyl Acetate, Polyphenylsulphone or Phenol-formaldehyde). By making acronyms for material alloys or abbreviations ZAMAK (Zinc + Aluminium + Magnesium + Kupfer[1]), HDPE (High-Density Polyethylene). Or take the name of the element (Nickel, Silicone, Titanium). DIY-Materials are named differently. In the case studies from chapter four, every designer named the material according to not only the composing elements or sources, but to the message they wanted to give (Coleoptera, Shaping sugar, Marwoolus, The New Age of Trichology). Designers are encouraged to provide a name for their material that could also contain a message and also be retained easily by people. When asking people who attended the different exhibitions about the materials they liked the most, they tend to respond with the material name first and a short description of it afterward. It is a confirmation of the strength of this idea. “I liked this fluff material very much which comes from the drying machine” or “This ‘never too lat(t)e’ that is made out of expired milk is a fascinating material.”

1. Kupfer is the german word for the element Copper.

Figure 9.5 *Example of Material Datasheets.*



B. Kingdom where it belongs

Having the kingdom of belonging in the datasheet provides essential feedback even before reading the whole sheet. Also, regarding the classification and categorization of information, this visual icon is critical to organize the database when the number of materials developed grow. Sometimes it is possible to have two icons in the same datasheet, as explained in **chapter five**. The kingdoms classification is not strict but loose and depending on the material, letting it belong to two different kingdoms can enhance its value.

C. Material properties

Like any other material datasheet, a description of the features is mandatory, as it allows the reader to understand the possibilities of the material. The description of both physical properties and sensorial qualities were blended inside these datasheets. This blend gives a better understanding of the material when the sample is not physically present. As discussed in the previous chapters it is important to spread this information in an open source platform for anyone to replicate the experimentation and create the material. Therefore, having technical information together with a sensorial one will be of great help.

Figure 9.6
Example of Material Datasheets.

D. Description

In the description, the designer tells the whole story: where the material comes from, what are the motivations, what sources of inspiration were taken into account and what is the expected vision. Like with any other material, suggesting an application will be counterproductive. Depending on the context, an application will be suitable or not. However, the materials experience vision work as a guideline to show what the material is capable of and what are the difficulties or challenges the material could face. This is a direct result of the tinkering process where the designers learn to "hear" the material. The iterative process of experimentation through tinkering develops a strong relationship between the material and its creator, and for that reason, the designer can express a vision.

E. Ingredients

Ingredients according to the FDA are the different constituents of any food, drug or cosmetic[2]. Ingredients are also constituents for any DIY-Material. Designers´ lack of scientific knowledge does not allow them to perform complex organic or inorganic formulations of a material and nor are they intended to. Listing the ingredients, on the other hand, gives the first step in this direction allowing the reader to understand which elements are present in the material. it is important to say that explaining the exact amount of each ingredient remains at the designer's disclosure. Some designers may want to protect their intellectual property of the material, like in any other design and may not tell the exact amount or will not list all the ingredients. Anyhow, in the datasheet, it is essential to include as much information as possible.

Ingredients may also refer to the components or other elements that make part of the material, whether they are electronics or other materials.

2. According to International Food Information Council (IFIC) Foundation US Food and Drug Administration (FDA) Food ingredients and colors chart.

F. Material Slogan

According to the Oxford Dictionary of English, a slogan is a short and striking or memorable phrase used in advertising[3].Designers are encouraged to add a slogan into the datasheet as an element to reinforce the message they want to express and to boost the materials experience.

3. https://en.oxforddictionaries.com/definition/slogan.

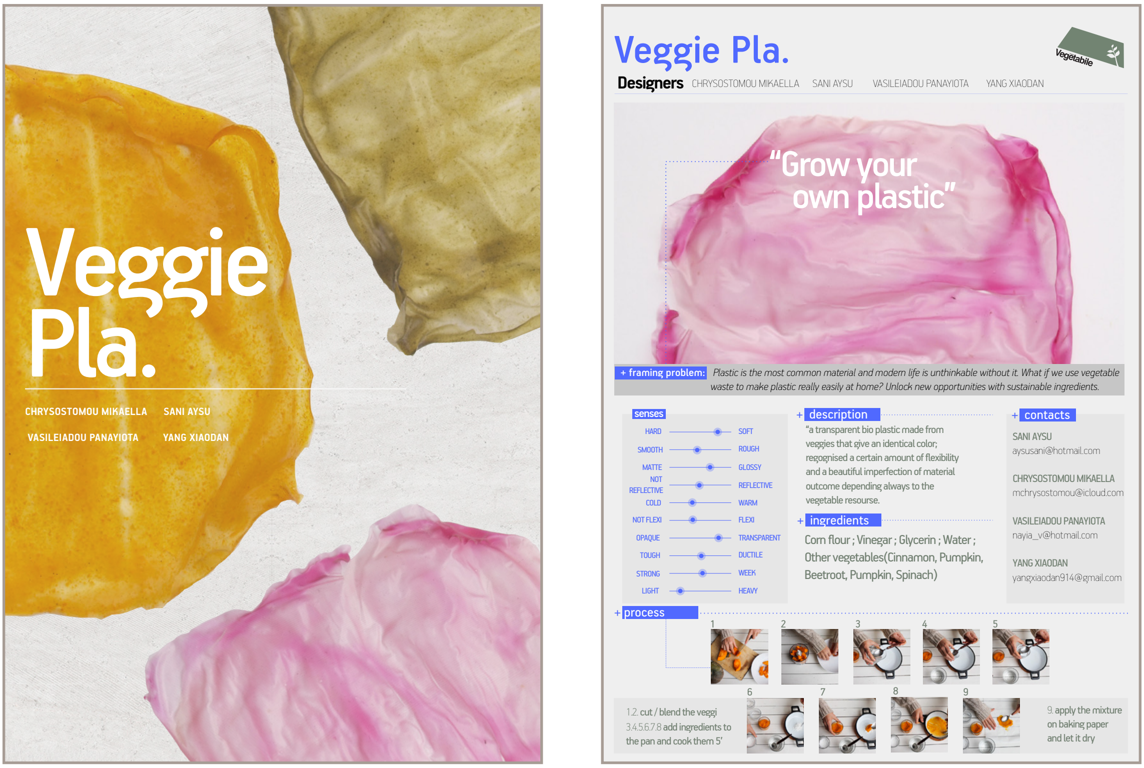


Figure 9.7
Example of Material Datasheets.

G. Key Steps

Every DIY-Material went through a series of experiments, tinkering processes and iterative refinement. Different case studies have shown how the designers give value to the material when the whole development process becomes an active part of the storytelling. The datasheet allows the designers to describe the most representative steps of the material development. This will serve as a guideline and visual feedback for the ones who want to replicate the material. Each step may include an image showing the main features of each level of experimentation and a short description of the actions that occur in this particular moment. Each designer is free to add as many steps as needed.

H. Key Shots or Main Images

The old expression "Use a picture, it`s worth a thousand words[4]" is of extreme importance when it comes to highlight and describe a material. As materials do not have a defined shape and they are not being easily recognized as an entity by many, it is essential to show their features and qualities with a good set of images. As noted in **chapter six**, when discussing the early observations on DIY-Materials aesthetics, in

4. This phrase is attributed to Frederick R. Barnard, who published a piece with the title "One look is worth a thousand words", in Printer's Ink, December 1921.

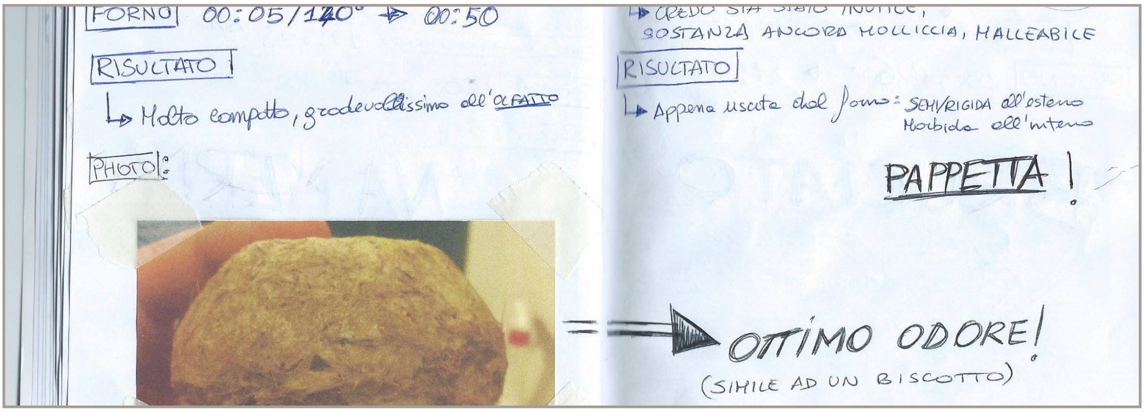
most samples it is possible to see the composition of the material in its surface or its volume. This feature is completely opposite to what happens to other STEM materials like metals, polymers or even semi-finished materials, where only through CMF, trims, and catalogues it is possible to highlight aesthetical features. Designers are encouraged to spend some time to do a small photo shoot of the material highlighting its experiential qualities. One image will become the cover of the datasheet. The others will complement the data. The additional pictures will be used for exhibitions, websites, and publications.

I. Designer credits and contact

The datasheet will always include the names and contact information of the designers who created the material. More than a way to give proper credit, it is also intended to build a network. The websites and databases where the different DIY-Materials are being included could become the building blocks to connect materials development inside the concept of future Fab Cities (Diez, 2012) through what we called the Materials Clubs. Physical and virtual spaces were materials and their developers interact and take materials, samples and projects to another level.

9.2.2. DIY-Materials Diary

Materials Tinkering is a design practice characterized by specific features, procedures, supportive activities and goals. This process aims to extract data, understand material properties, understand constraints and recognizes its potentialities (Parisi, Rognoli & Sonneveld, 2017). All this process is registered since day one. Design diaries or journals are guiding elements that allow the teams to conveniently and expressively convey details about the whole process (Martin & Hanington, 2012 pp. 66). One of the key elements of the entire DIY-Materials development is the careful collection of information of any kind. Achievements, failures, thoughts and inspirational sources need to be inside the diary. "You never know when a piece of information regarding your experimentation will become useful. Probably at the end of the project." This phrase is often said by the researchers to students at the beginning of the courses to encourage them to keep a diary (Figure 9.8). Nowadays, with the possibility to take pictures with mobile devices, designers capture an important number of images which can be wisely used to report the experimentation with the material. Combination of media is also suggested as it enrich the diaries with the



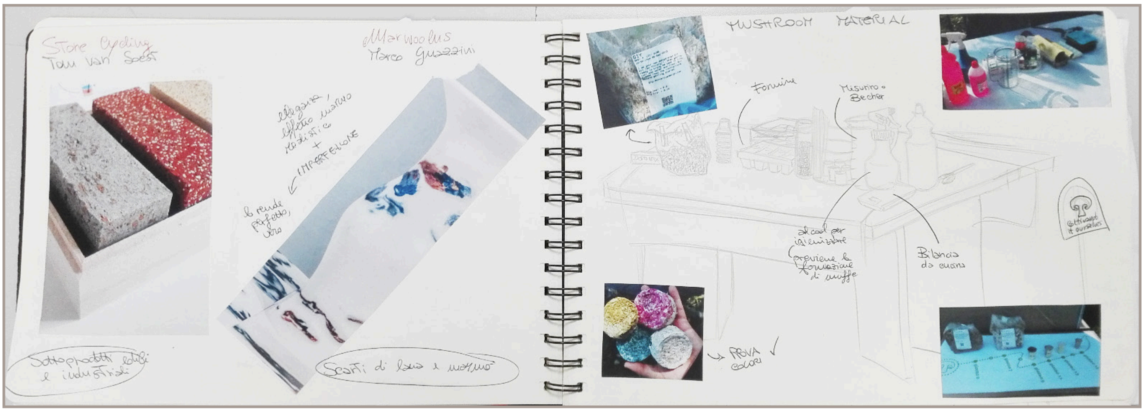


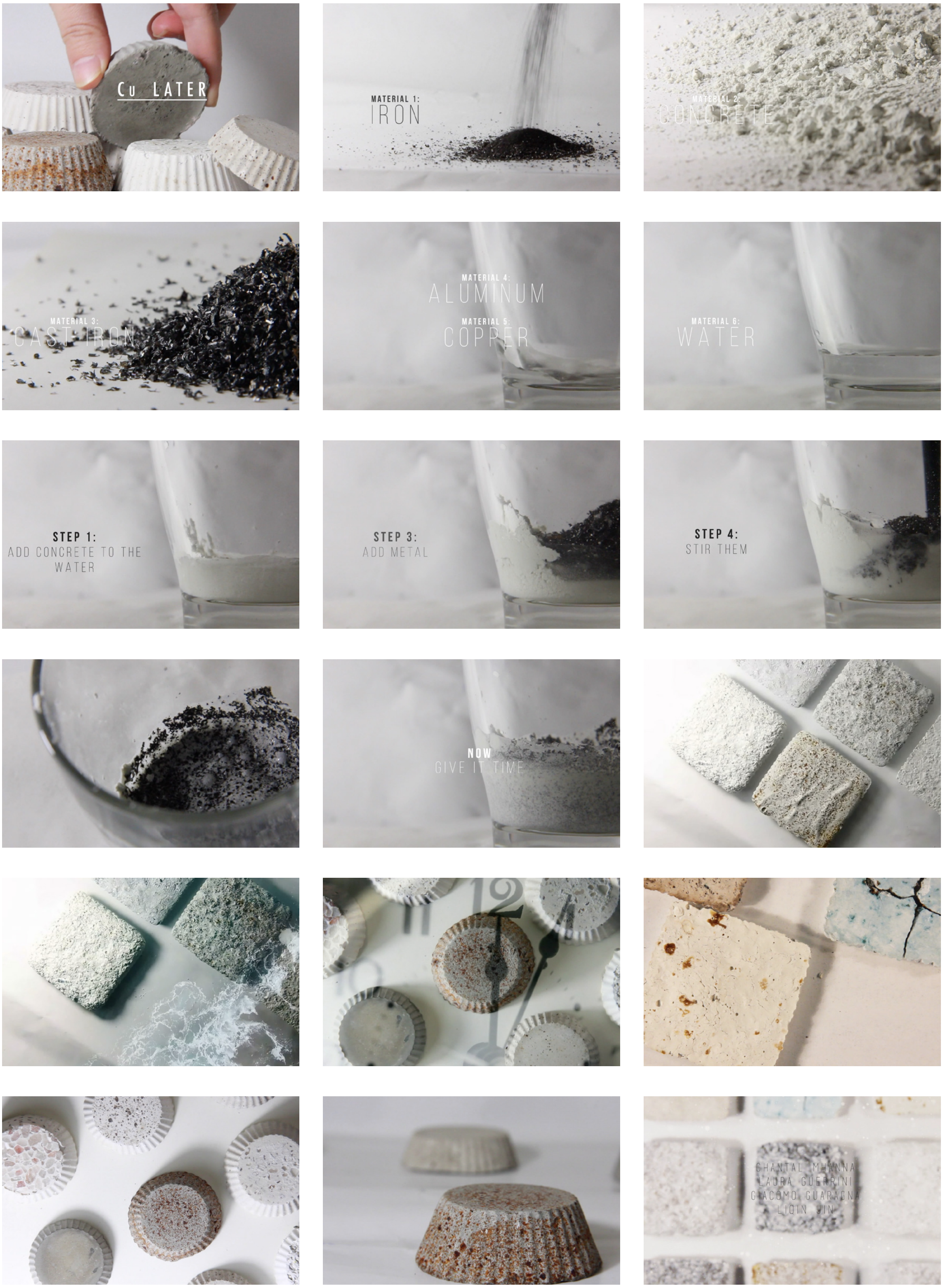
Figure 9.8
Examples of DIY-Materials diaries.

photographs taken with their phones, as well as sketches and writings of the different details around the tinkering phases and experimentations.

9.2.3. DIY-Materials Video

Designers are communicators. Through shapes, images, sounds, and all the different media available, design knowledge is used to communicate and express intentions. Together with the datasheet, the designers are encouraged to develop a video to tell the story of how they achieved a particular material and the whole meaning of this achievement (Figure 9.9). It is part of the storytelling of the DIY-Materials research. In 95% of the cases studied, either the designer develops a video, hires or invites a filmmaker and a photographer to help in telling the story of the material development. It is a powerful tool that traditional STEM materials do not have still as a standard feature. Is in this particular communication strategy where designers have something important to contribute to the field of materials.

Figure 9.9
On the next page. Example of a DIY-Materials video.


Cu LATER
MATERIAL 1:
IRON
MATERIAL 2:
CONCRETE
MATERIAL 3:
CAST IRON
MATERIAL 4:
ALUMINUM
MATERIAL 5:
COPPER
MATERIAL 6:
WATER
STEP 1:
ADD CONCRETE TO THE WATER
STEP 3:
ADD METAL
STEP 4:
STIR THEM
NOW
GIVE IT TIME
CHANTAL MHANNA
LAURA GUERRINI
GIACOMO GUARAGNA
LIQIN JIN

9.3. The Materials Generation Roadmap

There is a new generation of designers entirely different from their predecessors. Designers have today access to tools and sources of information that were unavailable to the designers of the past. Many different things can be made at incredible speed, and we have the power to change the course of societies looking for alternative ways to tackle the increasing wicked problems of modern life. Designers can generate materials, and the means to do it are more accessible. In this section, the different procedures are presented to achieve a material starting from a raw source that could be either taken from earth or recuperated from other already extracted sources. Everything is made with full respect to the current standards of design for sustainability and circular economy principles. Following these procedures will allow any designer to propose alternative paths to explore new product languages, new solutions for a particular problem and above all, to develop meaningful applications by transferring a material experience to the artefacts he or she or others will create with the material.

The different results of every procedure have been tested and described in this work. By following this series of steps, designers could provide meaningful alternatives to what the society currently produces.

The roadmap is not linear and could be followed in any order. Each project may encounter the necessity to follow some steps and skip some others. Some projects may suggest other new stages, and some projects will follow the steps together with product development. This roadmap will work as a guide having a clear understanding of which procedures support the achieving of a meaningful material proposal. It is deeply rooted in the findings and validation of hypothesis of this doctoral research but is not the one and unique method to follow. It can be combined with other methods, and it can be modified and further developed or debated. Keeping record of every step with all available media, will help to better communicate the results at the end of the project.

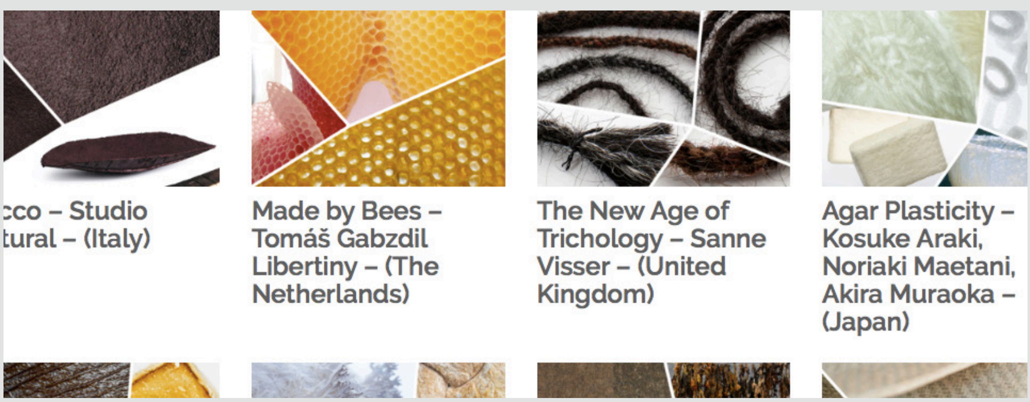
9.3.1. The Brief: Design from The Material

It is well known that the design brief ensures the designer to considers essential design issues and questions before starts to work. To achieve a proper material development process, the designer needs to consider standard requirements as well as define the purpose of the project. Timelines with tests and reviews may also be discussed. There is no standard time scope for a material development, but like any other design project, it is vital to define constraints regarding time and milestones. Budget is sometimes omitted, but is also suggested to consider a reasonable allocation of monetary resources which will allow the designer to perform experiments, develop DIY tools as well as be able to make tests in laboratories in the more advanced stages of the process.

The primary objectives of the project should be at least sketched in this part. Further on, also based on the results of the tinkering processes, the designers tend to refine the aims and goals of the project. However, during the studies of this dissertation appeared visible that designers since the beginning have a good idea of what problem or opportunity they want to tackle with a materials development. Notice that in this thesis the design process for a related application is not included. It is out of the scope of the doctoral research, and it is a process as complex as developing a material. In the brief, however, there should be specified the aims and times devoted to developing a particular application, according to the intended stream to follow, which will be explained at the end of this section.

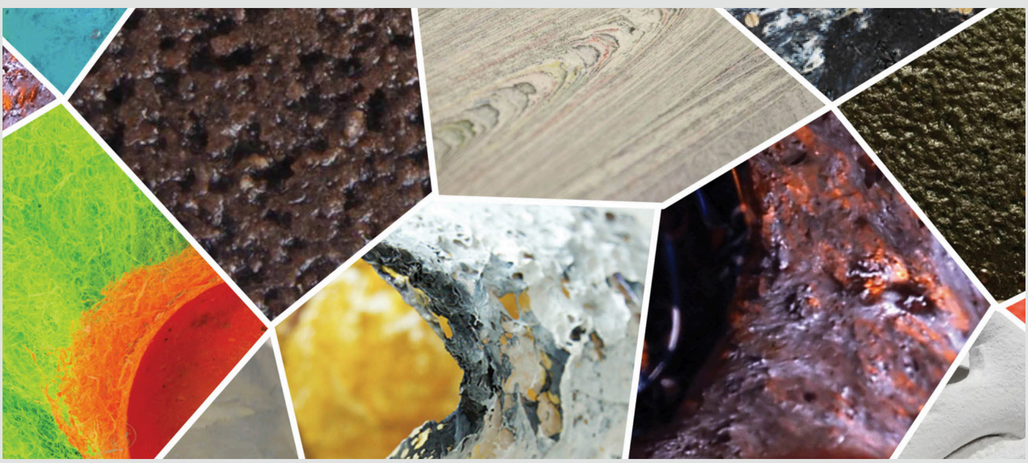
9.3.2. Case Analysis and Inspiration

Designers take inspiration from everywhere. **Chapter three** highlights some inspirational sources that many designers take into consideration when designing a project starting from the material. There are hundreds of books and magazines which provide significant sources of inspiration, and the web can also contribute. Chris Lefteri coined the term materials for inspirational design in early 2001 with a series of books which motivate designers to use a particular material by understanding its properties and uses. To make a material yourself, is important to research different cases and sources for inspiration. By doing so, benchmark cases similar to what is expected to achieve, allows an understanding of successes and failures and may help to leapfrog those cases with the different experimentations. It is part of the DNA of the designer to search for inspiration. Designers look for examples in art, architecture, science, and nature. To enhance inspirational research, is ideal to construct material boards, which are a collection of physical samples, pictures, textures and ideas that will guide the material development. The boards should not be seen as a finished work, they can be updated and upgraded during the different phases of the materials development, and at the end, they will become essential tools to communicate the materials experience. The material boards are great tools that allow to move from a simple collection of data to a meaningful interpretation of information.



9.3.3. Choose a Kingdom to Research and The Source

Choosing a kingdom of interest after doing in-depth research on inspirational sources will help to understand better what to do and how to do it. Concentrating on a particular kingdom, can help to observe among the different cases the different ways in which designers have worked with a material source. Understanding similarities between an idea of a material development and the ones of the kingdom is important for the development of a DIY-Material. Considerations, tips, experimentation settings, failures, and achievements could be of enormous help. More than one kingdom can be selected to analyse; this will depend on the material idea. As explained in **chapter four**, dealing with a biopolymer, for example, can be approached from kingdom Vegetabile, Animale or Recuperavit. It depends on the motivation and sources of inspiration, whether is something to grow or farm, or something to reuse or upcycle. Exploring the kingdom of interest deeply either in the databases or through the different places of the web, books and design exhibitions worldwide can be of great help. It allows to identify a DIY-Material very easy, regardless of the designer's intention on the project where is embedded. The aim of the whole kingdom categorization like any other in science is to provide a series of similar characteristics and relationships that could guide any further research.

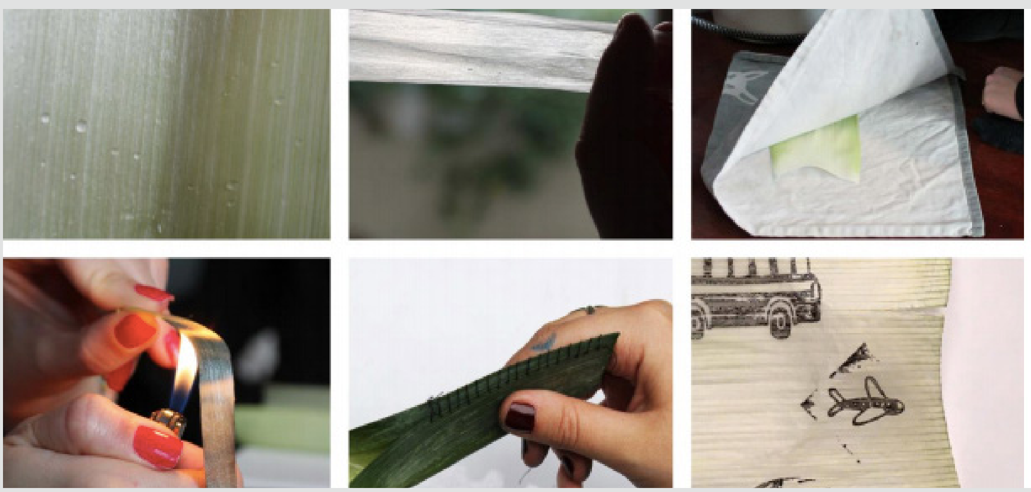


9.3.4. Explore the Theoretical Stimuli

Materials and Design is a growing discipline. Materials is a field of knowledge designers need to understand and enrich. Alesina and Lupton state that "Materials are like words. The richer your design vocabulary, the more solutions you can see and express. There are no good or bad materials. Each one has its place, consequences, and cost. Understanding materials is essential to design" (2010 p. 4). This research provided a series of theoretical stimuli into the second study on **chapter seven** selected to guide and nurture the DIY-Materials development. Concepts and theories around Materials Experience, the value of imperfection, dynamism, self-production, essential knowledge of chemistry, are fundamental to understand how to make a material. Adding any other source of knowledge could also nurture the project.

9.3.5. Tinkering with the Material

Material tinkering is a design practice characterized by specific procedures, supportive activities and goals. Material tinkering aims to extract data, understand material properties, understand constraints and recognize its potentialities (op. cit.). It is essential to have proper time and space to tinkering with the material. Once all is set, spend time with the material to get to know each other. Start a conversation without constraints. The more trials and tests with the material, the better understanding about qualities and properties emerge. Keep in mind that the result of the different tinkering phases will look incomplete and without a defined shape or structure, and some results will produce frustration. However, keep track of the different samples of material attempts and unique elements and achievements will become visible. Those insights can unlock a next step in the development process. Remember that tinkering according to Wilkinson and Petrich (2014) "It's thinking with your hands and learning through doing. It's slowing down and getting curious about the mechanics and mysteries of the everyday stuff around you. [...] when you tinker, you're not following a step-by-step set of directions that leads to a tidy end result. Instead, you're questioning your assumptions about the way something works."

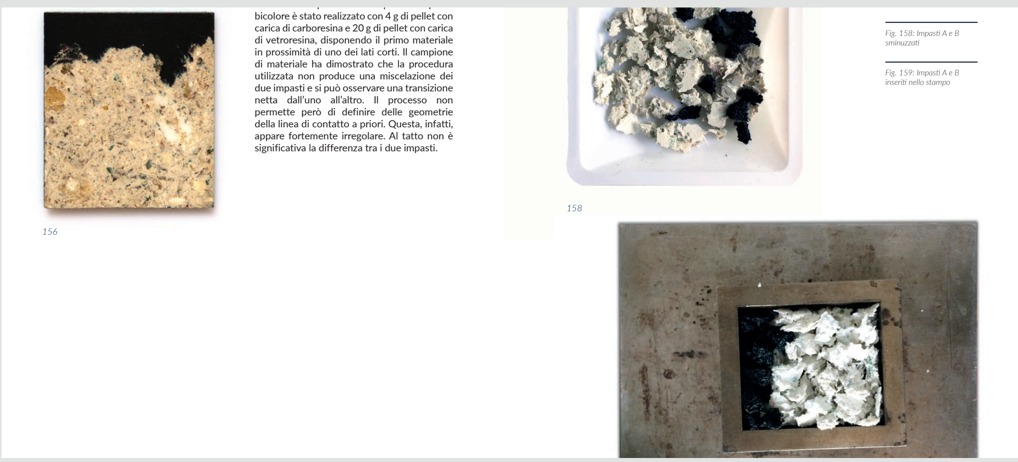


9.3.6. Materials Driven Design Method (Steps 1&2)

Material Tinkering is one of the strategies suggested by Karana, Barati, Rognoli and Van der Laan in the Materials Driven Design Method (2015). When it comes to materials development, is suggested to address this method considering the third scenario, which states: "design with a material proposal with semi-developed or exploratory samples". As the material is under development and probably will be a novelty, its properties will be further defined and tuned-up according to the possible applications to explore. At this point is essential to follow the first and second step of the method to obtain information not only from experiments and tinkering processes but also to gather insights from other people about the material. Take some time to present achievements to colleagues and friends, submit some samples to them and allow interaction. Valuable feedback comes from this interaction enabling improvements to the material. These interactions may suggest additional elements to include in a materials vision. At this point, the different experimentations come close to the initial idea when the brief was written. If not, do not worry, more iterations and exploration will help. Sketching a Materials Vision at this point will boost the material development. A better understanding of the capabilities of the material concerning experiential qualities and some physical properties, as well as the role of the material in the different contexts where the material may be used emerge at this stage. Also, the possible interactions that the material may elicit. In other words, at this point, the different characteristics that will later become part of the identity of the material become clear using this method.

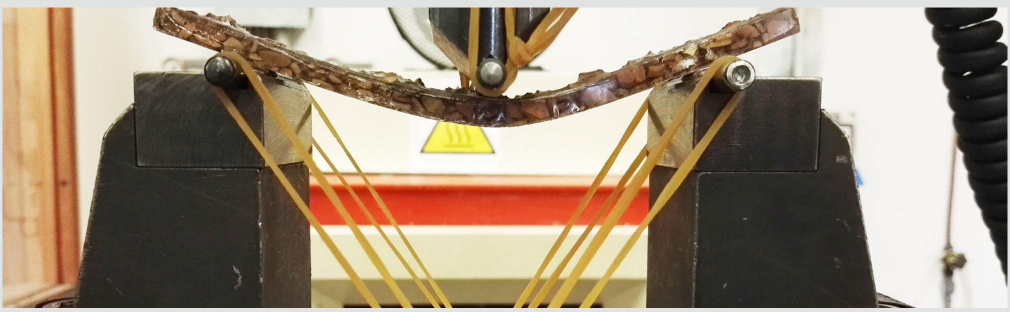
9.3.7. Iterations and Optimization

The light at the end of the tunnel comes at this point. The second and third study presented in this dissertation showed that almost all designers encounter troubles and difficulties during the experimentation phases. Most of the times, the material behaves utterly different from what they were expecting. It is a natural thing to happen, as the material in hand is unknown. The supposed behaviours are mere guesses. In the moment the material "talks", a relationship between the material and the designer emerges. With this relationship, everything changes. As expressed in the outcomes of the second study in **chapter seven**, the designers change the attitude towards the project, from being something to do and submit, to something they fall in love with. The different questionnaires answered at the end of the study suggested that they have learned more about materials in this phase that in their whole design education path. This feeling is the result of touching the matter instead of learning about it from charts and tables. The designer is probably more engaged with the whole project, and will probably have a positive mood. At this point it is important to start another round of experimentations, this time aiming to improve the samples. To do that, enhancing the experiential qualities of the material, exploring sizes and shapes that could express better the material identity and its capabilities is very important. Keeping track of everything is key.



9.3.8. Material Characterization

Once the material development has reached a mature stage in the development process, it is of great help to perform basic characterization tests. Any macroscopic techniques such as mechanical testing, thermal analysis or density calculation will allow the designer to obtain advanced information about the material. Manzini suggested that new materials don't necessarily come from research centres and laboratories (1986, p. 42), and through this thesis work is visible how this statement is more valid than ever. However, designers who create a material, must understand the role of laboratories for testing and make good use of them. Through the different projects explained in **chapter eight**, became clear how important it was for the various projects to approach a laboratory to perform standard testing for characterization of properties. From the designer's side, it was of great help to understand which type of test may withdraw relevant information about the material features. From the laboratories angle, it was a challenging task, trying to find the right standard test to perform (Following ASTM, EN, ISO or DIN standards) for an unknown material sample. In this mutually beneficial relationship between designers innovating with materials ideas, and materials experts providing their knowledge to understand behaviours and properties is fundamental to take the DIY-Material development further. Ashby and Johnson said "vague rhapsodies about the wonders of a new material can serve to stimulate interest, certainly. But if you want to design with the material you need to know the bad news as well as the good [...] Emerging materials can have awkward adolescence during which their true character only slowly emerges" (2002, p. 163).

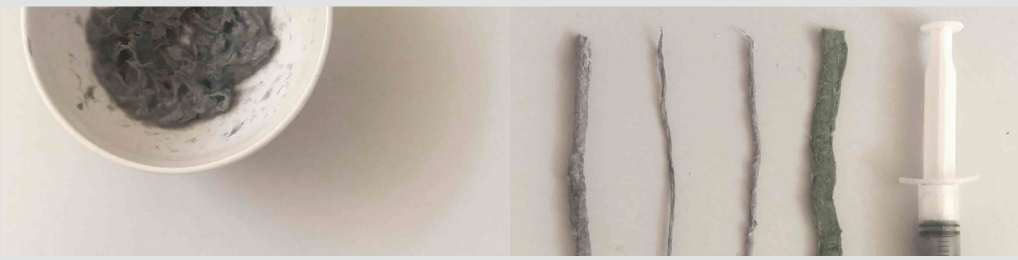


9.3.9. Material CMF

The DIY-Material is a development from a designer's perspective and is structured under a project brief like any other product. It can be designed and refined enhancing the identity and the characteristics that will define the material's personality. At this point, a conscious exploration on different patterns, textures, colours, composition or a combination of material samples will enhance the material affirming the identity and the possible characters it can acquire to elicit a particular material experience. Improving the tactual experience of the material (Sonneveld, 2007), developing a tailor-made expressive-sensorial Atlas (Rognoli & Levi, 2005) of the material with a collection of samples and parameters for selection, will allow the material to mature from the qualitative point of view. All the different insights and information obtained from the user studies, the characterization phase and the experiential knowledge acquired by experimenting with the material, can be carefully arranged and explored to improve the design of the material sample, its appearance, and its sensorial characteristics. CMF being a meta-design strategy closer to the concepts of advanced design (Celi & Celaschi, 2010) invites to explore different trends around different design styles and forecast the possible languages the material could propose when it will be applied. Imagining speculative uses rather than fixed applications could give the material more capabilities in the long term.

9.3.10. Manufacturing Possibilities

Exploring possible shapes and forming capabilities of the material is crucial and is part of crafting the intrinsic knowledge of product design. It is not sufficient to develop a material and present it in a regular bi-dimensional form. Qualities and unseen properties may be missed by keeping the material samples in a flat format. Part of the identity of the material is related to its behaviours when becomes a solid volume or a hollow shape. If the material is curved shallow or deep, it will produce an effect that can be controlled and enhanced. Exploring forms and shapes is crucial and fun for the development of the material. It is a refined step that requires knowledge about the many ways industry and crafts shape, join and finishes things. The different demonstrators and studies of various shaping techniques add a dimension to the material closer to the possible applications. It is a valuable source of information regarding the future product developments of the material, or for those who will be inspired by the material and want to use it further. Keep in mind that all manufacturing process the industry uses come from a fundamental principle of crafts. Each manufacturing process can be easily applied with common DIY tools once it is fully understood (Ayala-Garcia, 2015). Different DIY-Materials are born thanks to experimentation on the transformation techniques, as seen in **chapter four**. Twisting and hacking manufacturing techniques could lead to unexpected results and shapes that are very difficult to achieve with the standards of the industry. Gaetano Pesce stated in the early eighties that "humans are different and change over the course of life. The objects around us have the same right" (Martino, 2007 p.50). Keep in mind that transforming a material can also mean understanding the way the material may change over time. DIY-Materials differ from STEM materials as are not expected to be perpetual.



9.3.11. Narrative & Storytelling

As seen in the different cases in **chapter four** and explained in depth in **chapters five and six**, designers use storytelling as a tool to describe the entire process. This tool is particularly helpful to tell everything about a newly designed material. Keeping track of the whole process is key. Since the very beginning, it is important to record, with different media, the advancements of the project. It is recommended at this point to hire a photographer or a filmmaker. By understanding all the various elements of a materials development, they could help thanks to their background and knowledge, to find the right way to tell the whole story. This step is crucial for the material. Regardless of the trajectory the material project will take, a valuable set of samples which are available may help to build up a story. The different features of the material highlight the drivers and motivations behind the project, the sources of inspiration, tools developed and tests performed. Everything according to a vision of the materials experiences enhanced with multimedia tools.

Figures 9.10 to 9.20
Reference images for each step of the DIY-Materials Roadmap. See List of figures for image credits.

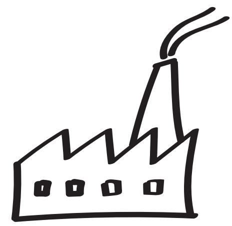
9.4. Possible streams for DIY-Materials

At this stage, the material is mature enough to continue on a path towards a possible use. Exploration of different applications and tune-up of characteristics accordingly is the next step. It is crucial to analyse technical potential, environmental impact, social or local opportunities for development including business opportunities according to the project. There are three possible streams for a DIY-Materials development, based on the different findings of the studies performed during this doctoral research (Figure 9.21). Each stream needs a proper setup, collaboration of other stakeholders and a development plan. It is probable that the material suggested which stream to take during the previous phases, but at this point is important to have a clear idea on which path to take. Depending on the path, analysing intellectual property actions and open source scope may be relevant to consider.

9.4.1. Stream One: Designers own small scale production

For a design professional owning or sharing a studio with other designers, a DIY-Materials pathway could bring innovation and new directions for future projects and clients. Similar to the different designers studied in **chapter four**, the designer's portfolio may contain an experimental work on materials research that can guide the development of various projects, limited editions, and collections. It can help also to define the DNA of a studio and a design philosophy. Prototypes and installations showing a vision and forecast of scenarios to attract customers, investors or the press can be made with a materials development. If a designer is starting a professional career, could be interested not in opening a studio, but in making a new entrepreneurial venture such as a start-up. For sure the material development will not become a start-up per se, but it will provide the tools to develop a project, search for the right team (from other disciplines), find a market need and develop a proper business model to present to a hub or investors and move on. As any start-up is an organization formed to search repeatable and scalable business model (Blank & Dorf, 2012) and is designed to deliver a new product or services under conditions of extreme uncertainty (Ries, 2011), starting from the material can be the correct step. Cases studied in **chapter four** such as GIY from Ecovative or FiDU from Oskar Zieta have shown how a design project and a business initiated from the material. Currently they are examples of a growing venture with products and patented processes providing new objects and new languages to the market. Scalability is something each project will need to measure independently. Form experience, it takes many years to tune up a material before it can be scaled to industrial series. DIY-Materials should not follow the rules of STEM materials concerning scalability and fine tune for industrial applications. However, if the material has the potential, this could be a stream to consider.

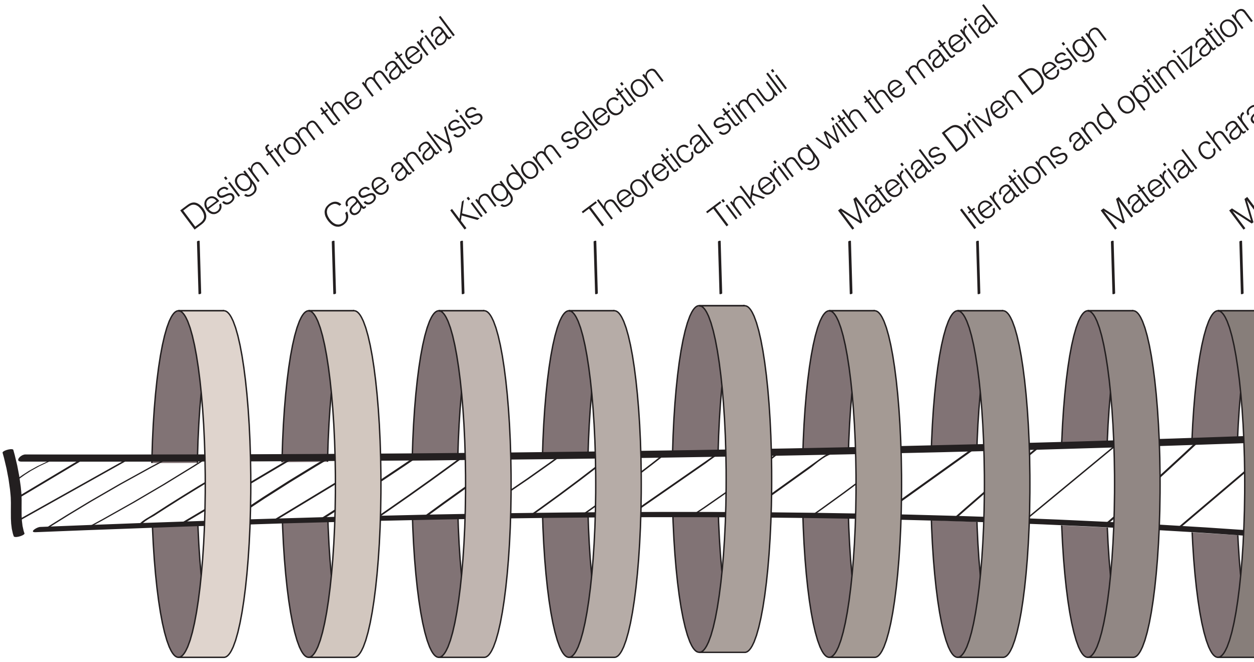
9.4.2. Stream Two: DIY-Materials adopted by industries and scaled up for mainstream production



In **chapter three** was explained how an experiment and the development of a material idea can be the holy grail from entire industries and could define a whole generation of products and product languages. Successful stories like the one of Fratelli Guzzini and their road to success by the use of PMMA (Poly-methyl methacrylate) in the early 1930's as surrogate to horns, opened a whole new product language and products that are still recognizable today. The new material like any other new development was expensive and difficult to acquire, but with the "adoption" of this material by the company and the transformation of products exalting the experiential qualities and the physical properties, gave the material one great opportunity (Rognoli & Santulli, 2014). This idea of an adoption of a material - as this stream suggest - can occur to DIY-Materials as well. With the constant pressure that the market put into the different industries to innovate, a young material development like a DIY-Material can be essential to achieve innovation. Some of the results of the second study have been presented to different companies in informal meetings by the research team, and unexpected reactions emerged. Manifestations of interest in exploring developments of the material proposals have been always present in the meetings. Sometimes industries need fresh and creative ideas to move away from the fixed structure (MacKenzie, 1998), and new materials development from a designers' perspective can be a refreshing alternative to overcome market difficulties for a company.

9.4.3. Stream Three: Developing DIY-Materials for social change

This is the stream where the DIY-Materials have the best chance to operate. The other two streams could indeed work, but it is uncertain

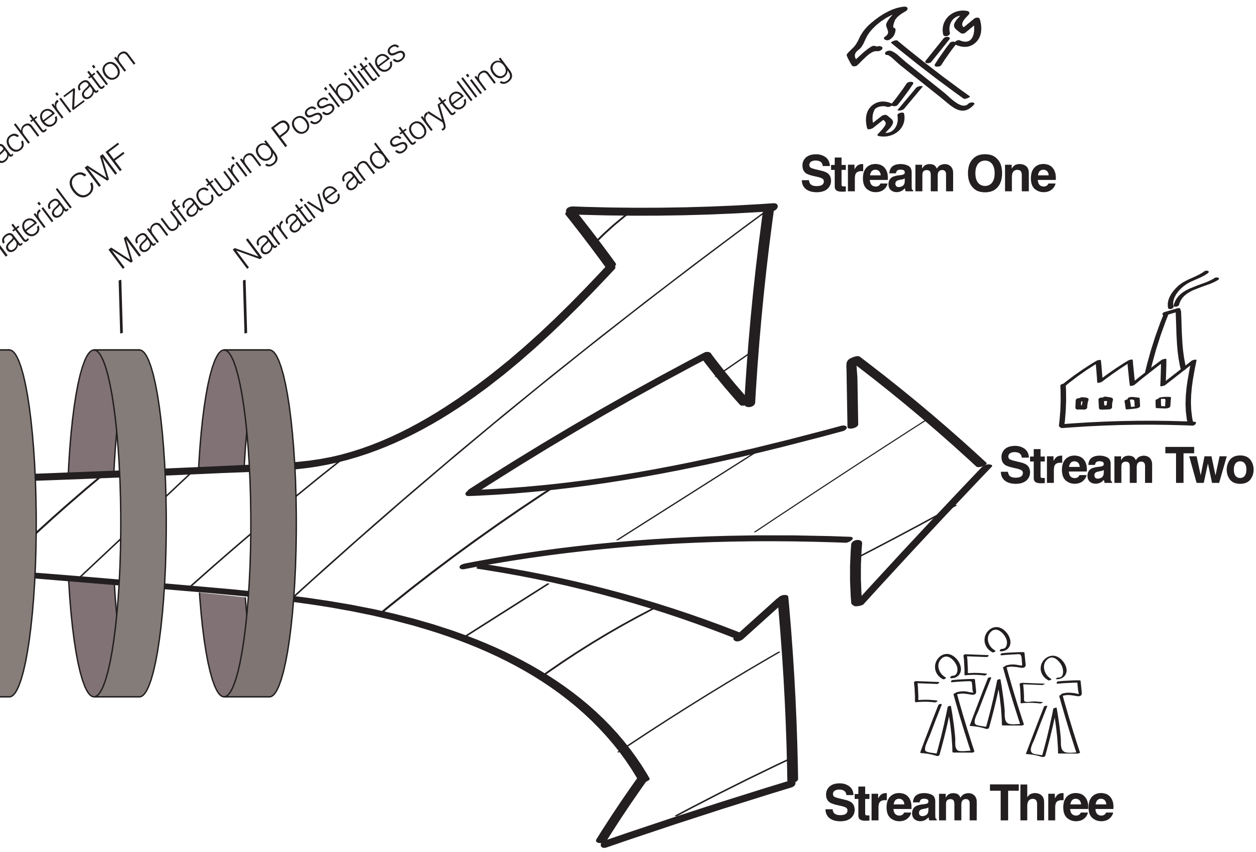


DIY-Materials Development Pathway

Figure 9.21
The DIY-Materials Roadmap schema.

if those materials will compete with well-established STEM materials for a place in the mass production market. Instead, it is probable DIY-Materials could have a better and more meaningful role, operating where traditional STEM materials struggle to perform. In many communities around the globe from any nature, there exist different problems that could probably be solved with a DIY-Materials approach. Societies are composed of many small realities with different needs that are left unattended by mass consumerism. As STEM materials are developed mainly to be scaled and produced in enormous quantities, to be financially viable, profitable and globally distributed, many materials appear inaccessible or unviable for different sorts of applications in the local scene. A DIY-Material can be an alternative in these scenarios and could transform small realities by providing opportunities to enable circular economies and social innovations.

A DIY-Materials approach could work towards economic and cultural diversification within a particular local reality. Different local-orient-



ed initiatives starting from a materials and resource analysis like the one proposed in this chapter can spark a series of projects to enable participation of a particular social fabric, constructing new territorial ecologies and resilient ecosystems towards sustainable wellbeing as Manzini proposes in his book about the fundamentals of design for social innovation design when everybody designs (2015 p.202). Bringing variety into the overall ecosystems of a society with new materials or starting with a material development by searching for a local resource to exploit, it is possible to regenerate the local social and economic fabric. As seen in **chapter eight** in the thesis work of Karen Rodriguez, by addressing a particular problem through a material proposal of a local unseen resource, it is possible to enable different actors inside the community to operate. New empowered local farmers, artisans, and merchants could make good use of a local resource and build societies capable of living well independently and connected to each other. As appear visible in **chapter four**, by exploring resources, that come either from the extraction of local sources of any kind or by recuperating existing mined resources, it is possible to modify societies by transforming materials into something more meaningful instead of throwing them away or leaving them to waste. There are just so many free resources out there waiting for a trained eye to mine them, that it is just a matter of time to see circular economies and social innovations showing the potential that many materials and "obsolete" products can provide. They will become alternatives for future sustainable societies.

9.5. Testing the Roadmap

To validate the Materials Generation Roadmap, a former student who participated in the second edition of the Designing Materials Experiences course was invited to participate. She also expressed an interest to elaborate a thesis work exploring a DIY-Material, developing the thesis following the proposed set of incremental steps of **chapter eight**.

9.5.1. Re-Surface Project

Thesis Setting: DIY-Materials exploring possibilities to tackle Cradle to Cradle principles and Circular Economy Settings.

Background

Originally form Naples, the student was interested in understanding the lifecycle of a material that allowed the flourishing of a whole industry, particularly in Italy after the second world war. GFRP (Glass Fibre Reinforced Polymer) is the standard material suitable to construct large-scale boats, canoes and other means for navigation. Different from what happens to other means of transportation like automobiles, when the ships are no longer used, they are dumped or abandoned on the coast or the beaches, and many of them end up sunk below the coast water. The student found that according to UCINA[5] (2013) there are 75.000 nautical units non-circulating, with an approximate weight of 53.460 tons of GFRP. This enormous valuable resource can be recuperated through chemical decomposition processes such as pyrolysis to recover energy or by grinding operations to obtain fillers. The student earned the possibility to work with the national research council of Italy (CNR) who is performing a series of studies and has developed a series of patents to recuperate GFRP through a process called ETE (Emulsified Thermoplastic Engineering[6]). The thesis work aimed to attribute a new identity to

5. UCINA Cofindustria Nautica is the Italian Marine Industry association.

6. patent: (PCT / IT2007/00084 WO /2009/072150).

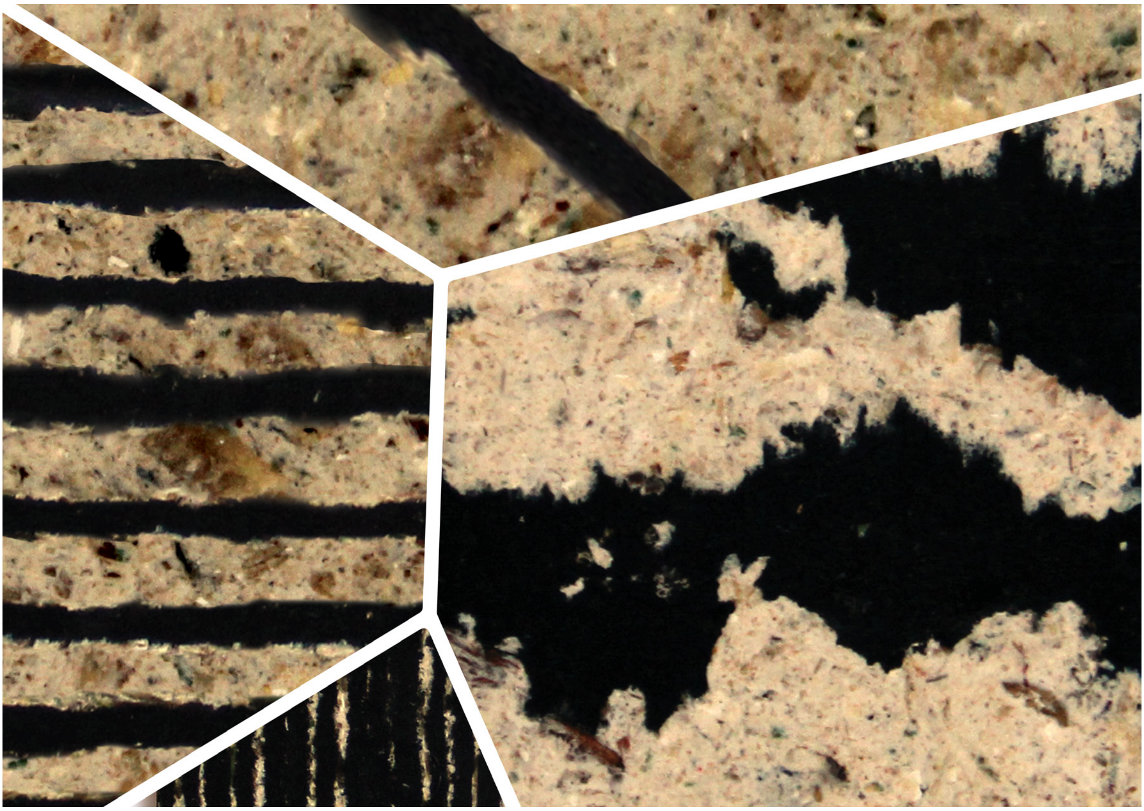


Figure 9.22
Re-Surface Material Board.

the recovered material, derived from the ETE process, and, working on the perceptual aspects, to give it an added value designing new materials experiences.

The following pages provide a short explanation of how the designer performed the study following the proposed steps of the roadmap.

The Brief: Design from the material

The designer was asked to understand the whole ETE process and the derivative materials. Additionally, she was requested to explore through the DIY-Materials roadmap, all possible transformations that the base recycled materials can have to achieve a new identity.

Choose a Kingdom to research and the source.

For the designer in this particular case, the kingdom of DIY-materials was clear from the beginning of the project which is Kingdom Recuperavit.

Case analysis and inspiration
The designer explored the different materials belonging to kingdom Recuperavit where special attention to upcycling recovered materials (Sub-category: recuperating industrial sources).

Explore the theoretical stimuli
For this project, the designer analysed the theoretical stimuli occurred as follows:
1. The DIY-Materials and the Kingdoms (Rognoli et al. 2015; Ayala Garcia et al. 2017).
2. (Circular Design Ellen MacArthur Foundation, 2013).
3. Design Primario (Trini Castelli & Petrillo, 1985).
4. The Materials Experience (Karana, 2009; Karana, Pedgley & Rognoli, 2014).
5. CMF Design (Trini Castelli, 1985; Becerra 2016).
6. Design for Sustainability (Manzini & Bertola, 2004; Vezzoli and Manzini, 2008).

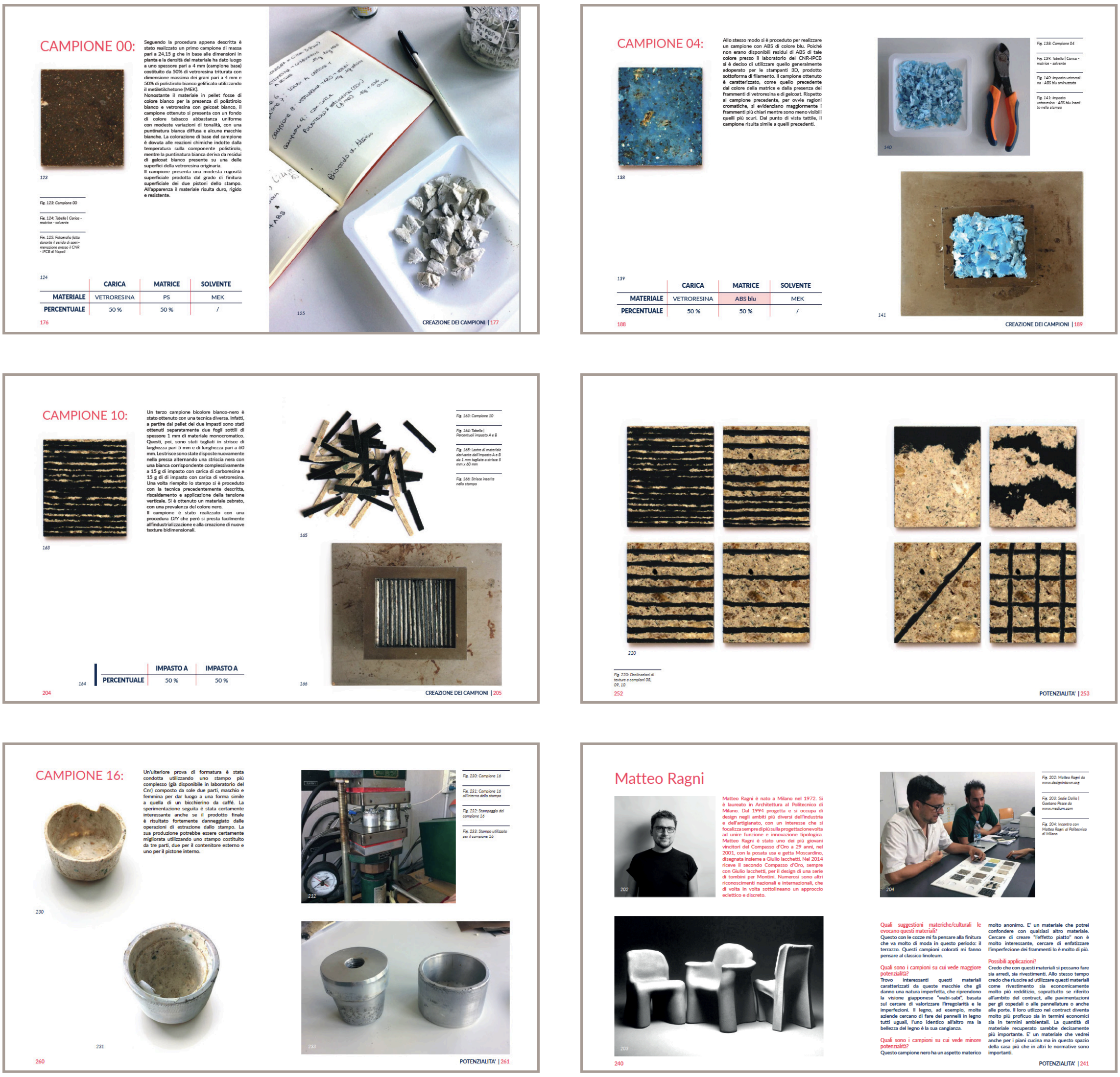
Tinkering with the material
As the base material was developed inside the national research council of Italy CNR, the designer was able to perform the whole tinkering process inside a laboratory, supported by material scientists (Figure 9.23 a-c).

Material Characterization
The CNR is conducting the characterization of the different material samples. As the designer is collaborating in close contact with material scientists and therefore it is easy to tune up the materials.

Material CMF
Different samples were carefully developed by the designer considering highlighting visual and tactile configurations (Figure 9.23 d).

Manufacturing possibilities
The designer developed different moulds to test forming capabilities of the material to gain shape. The processes tested were Compression molding, Thermoforming and Machining (Figure 9.23 e).

Telling the story
As a possible incremental step, the designer was requested to inter-



view professional designers of the Milan area to present the material samples and to obtain feedback from different professional points of view. This lead to additional information about the perception of the material and the possible opportunities towards the application (Figure 9.23 f).

For further information regarding the project and a more detailed explanation of the explored topics refer to (Aversa, 2018).

Figure 9.23
The DIY-Materials Roadmap tested within a project.
(a-c) Exploration, Tinkering and Evolution.
(e) CMF.
(d) Manufacturing.
(f) Storytelling.

9.6. DIY-Materials on tour

The studies of this dissertation were developed to test in an academic environment, the capabilities for designers to create materials. The outcomes were a series of material samples with the potential to be carried further into more mature levels. In addition to these developments, the methodology used on the courses and thesis works could be explored into other scenarios. To this aim a series of workshops under the name of DIY-Materials on tour were created (Figure 9.24). It is an ongoing project and through this academic experience is expected to spread the DIY-Materials theory and invite the different receivers of this experience to add their materials into the database.

The first experiences of this kind outside Politecnico di Milano were:

(2018. June). The DIY-Materials and the city - Workshop: Mine the City Lab: Matterathon - June 2018, Border Sessions, Tech Culture Festival. Den Hague, The Netherlands. https://www.bordersessions.org/lab/mine-the-city-lab-matterathon-day-2/

Figure 9.24
The DIY-Materials on tour during the Creative Marathon 2017, Elisava, School of Design and Engineering. Barcelona, Spain.

(2017. December). DIY-Materials on Tour. The expressive-sensorial qualities of self-produced bioplastics - Workshop at the Creative Marathon 2017, Elisava, School of Design and Engineering. Barcelona, Spain.

(2017. Ocrtober). DIY-Materials on Tour. Workshop at the ZHdK, Züricher Hochschule der Kunst. Zürich, Switzerland.

Different initiatives in other schools and universities are being explored as means to disseminate the DIY-Materials theory.

9.7. Future of material libraries

9.7.1. Materials Made @

As explained in **chapter three**, the material libraries were created to provide a service to designers and architects who were looking for a broader source of inspiration and encounter the right material for their project. As a library of books, these are repositories of knowledge, but instead of books, they contain materials (Miodownik, 2007). This dissertation showed how designers are capable not only to work with the materials but create new ones. All knowledge acquired during the experimentation phases and the phase of setting up the material should have a place where they can be organized and exhibited. Together with the database, all DIY-Materials should have a physical space to exist. Material libraries are the perfect environments as they are the place where people can go and physically interact with matter. The Materioteca of Politecnico di Milano, accepted to host and archive the different materials produced by the designers into what is called DIY-Materials made @ Polimi (Figure 9.25). The data

Figure 9.25
The DIY-Materials exhibition inside the materioteca of Politecnico di Milano.

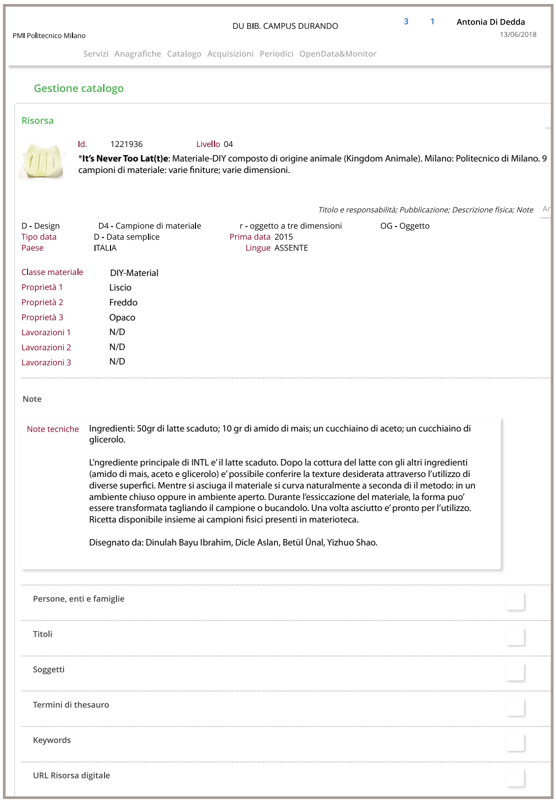


Figure 9.26
The DIY-Materials datasheets translated into the indexing and categorization system of the library at Politecnico di Milano.

is being organized to fit the current standards of the indexing and categorization of the library (Figure 9.26). The Idea is that the concept of "made @" could spread around and each material library whether academic or business-oriented could showcase and allocate materials developments from local communities. Further information regarding this project is available at: La Materioteca del Domani "The Materials Library of Tomorrow" (Pellegrini, 2018).

9.8. Discussion

In this chapter, the main focus was on the different outcomes of the conducted research. Hypotheses were satisfactorily tested in an academic environment, and the results are condensed in this section. Various participants in the studies explained in the previous chapters provide valuable insights. Indeed, without their contribution, the research would only remain in an exploratory phase. It is now possible to see is how the different projects from the various studies were able to produce material samples from a DIY-Materials perspective. The number of obtained samples allowed to validate the hypothesis, and answer different questions on how designers can develop materials.

In this chapter, the aim was to organize all the different insights in a series of steps and consideration to keep in mind when venturing into a DIY-Materials development. The various steps when followed together can end up in one or more of the possible streams presented in this chapter. The streams here introduced are not the only ones, and probably some others may emerge in the future. However, for this dissertation was essential to highlight the different scope and alternatives towards application that such type of materials has compared with traditional STEM materials. The DIY-Materials Roadmap should not be seen as a method. Methods tend to be strict in their sequences. The DIY-Approach should maintain its flexibility and versatility to grow and evolve. There is still plenty of space to keep testing this approach, especially outside the academia.

9.9 Conclusions

The different studies produced during this dissertation in addition to the material samples and physical results are several elements enriching the DIY-Materials Theory. In this chapter, it was possible to see the different outcomes of the studies in a series of steps and dissemination ideas. A test of these steps confirms that the DIY-Materials theory could produce high-quality materials samples. For sure it is not the only one, and different designers that were subject of study in the exploratory phase worked on materials without following this theory. However, by following this theory, similar results can occur, and possible alternatives to standard STEM materials can emerge.

This chapter works as an individual element to follow when someone wants to start a DIY-Materials development. It is connected with the rest of the dissertation but is organized in a way that the section with the set of steps known as a roadmap can be printed or projected as a reference during the experimentation of a material development. The outputs of the whole dissertation which are condensed in this chapter invite to study the phenomenon and comprehend the possibilities design have to offer to the materials science domain. It shows the power of knowledge share as well as the organization and order needed when dealing with materials development.

Chapter Ten

Culmination of the Resesarch

10.1. Results of the doctoral research

This doctoral research on DIY-Materials contributed to the field of materials for design by understanding emerging materials experiences that designers are developing in the past two decades. Different studies conducted and different results of the studies build up a DIY-Materials theory and are the core element of this dissertation.

The exploratory phase in this investigation allowed the formulation of the DIY-Materials kingdoms. This categorization into five kingdoms based on sources contributed to a better understanding of the phenomenon. After one hundred cases were categorized, each kingdom started to highlight particularities compared with the other ones. All cases inside a kingdom shared common attributes, drivers and sources of inspiration.

The fourth chapter provided the categorization and subcategorization of the DIY-Materials phenomenon by analysing and organizing the different cases. Making this categorization was a vital step of the research as it helped to improve understanding of this phenomenon. Different to what was initially published by Rognoli et al. (2015), inspiration came from the work of the Swedish botanist, zoologist, and physician Carolus Linnaeus called Systema Naturae (Linnaeus, 1740) - known as Linnaean taxonomy. This taxonomy gave to the classification of the phenomena a remarkable and delightful source for naming the categories. Apart from the first three categories similar to the ones of Linnaeus, other two families of cases were forming also based on their primary sources more related to the human intervention.

According to the Working Hypothesis (WH1) posed at the beginning of the research: *The DIY-Materials phenomenon tends to grow. There should be a way to organize it to allow a better understanding.*

The categorization of the DIY-Materials into kingdoms prove right this hypothesis, as it provided scientifically order and allowed a better framing to understand the phenomenon.

Chapter five presents an evaluation of the different cases collected. The qualitative and quantitative evaluation of the cases inside the five kingdoms provides valuable data to confirm Working Hypothesis (WH2) which states: DIY-Materials emerged from the creative fields of humanities. There should be a gap that traditional STEM materials are unable to fill. The DIY-Materials phenomenon is growing, and the different evaluation instruments developed to examine the cases allow a greater understanding when is divided into kingdoms. The different characteristics of each kingdom appear visible by reading both qualitative and quantitative data. They also showed a gap. The development of an instrument to evaluate each case by the different sources highlighted how the ability to do with the hands as well as the training on crafts were taken for granted by designers. This gap became one of the critical insights of the study as different from what happens with traditional stem materials which are developed in laboratories or large industrial infrastructures. The designer creates the material with strong physical and sensorial contact. The different features of the material are transformed and improved with an evident sensitivity and craft skill. Thanks to that particular finding, the formulation of the test phase became mandatory for the research.
The similarities that the different cases inside a kingdom have, emerge when the single case evaluations are put one on top of the other. From the data extracted by the evaluation instruments, it is possible to conclude that each kingdom is starting to show a particular sensorial unity. The aesthetics perception of each kingdom differs from the others. This perception, when further evaluated, will provide more descriptive characteristics inside each kingdom, recognizable also by every single material.

Chapter six presented an extension on the study of the kingdoms with a sensorial aesthetical focus. As the working hypothesis (WH2) suggested, the creative fields were filling a gap that traditional sciences were unable to fill. Aesthetic and sensorial expression of the DIY-Materials demonstrated a particular approach highlighting different experiential qualities. Therefore it was necessary to conduct a study on that front. The different studies on aesthetic attributes and qualities of materials developed by different scholars were crucial to evaluate the emerging class of DIY-Materials. Such alternative materials can create balance in a material world that is currently submerged by an aesthetic of perfection. Homogeneity and uniformity, precision and repeatability are dominating the materials arena, thanks to the current industrial state of the society. By referring to how the ancient Japanese tradition of Wabi-Sabi exalts the beauty of the imperfect things, this chapter provided a visual explanation of how those values can be tracked and clearly identified in the DIY- Materials Kingdoms. After an extensive evaluation of the different types of materials inside each kingdom, it is possible to create a general picture that describes the entire family by collecting and listing the similar attributes that emerged.

The third study presented in chapter seven evidenced how people with any knowledge on crafts (design students from different backgrounds such as product, fashion, interior, communication, and design engineering) were able to develop a material thanks to a physical interaction with ingredients and sources through material tinkering. The resulting work of the participants of the first edition validated the first Test Hypothesis (TH1) which state: There is a relationship between knowing how to craft things and materials development. It is possible to conclude that the level of competencies of the participants who enter into a DIY-Materials development is vital. It may not be crucial in the development of a material sample but is evident in the participants' ability to sensibly and sensitively work with matter. Creating a collection of material samples, improving features and applying design related knowledge improve notably the quality of the DIY-Material at the end of the development. Participants with inadequate knowledge of crafts have shown a weak material development in the study compared with the ones who are more craft-oriented.

Test Hypothesis (TH2) suggested that starting material development from a particular source has an effect on the final material developed. The highest number of samples produced by participants appeared under Kingdoms Vegetabile and Recuperavit. This demonstrates a higher tendency to use the local resource. This insight can be seen as a limitation as it conditions a type of result but can also be seen as an advantage as societies tend to look for local, sustainable solutions inside circular economies.

Test Hypothesis (TH3) suggest DIY-Materials were the result of motivations other than what STEM materials commonly have. The study also revealed how important it is for a material to tell a story. The different phases of the story must be coherent and according to the different media used to communicate the material experience vision. The study showed that the more attention a team dedicated to the achievement of coherent storytelling, a better result of the whole project arrived. In other words, the weakness of the different material samples at the end of the study was due to the incapability of the participants to tell the whole story of the intention to develop a material out of a particular source. The story is not only expressed by a video or a diary; the samples were also elements carrying the different stories behind the development. The material samples were the ones able to support the future visions for an application when they embedded storytelling in their surface by showing scars, blends and other elements of the tinkering process in a proper way. When the participants acknowledged what the material could show, they highlighted a particular feature during the presentation of the final result. This story allows the showcasing and presentation of the material to possible stakeholders that could help to push the material onto a higher level.

The fourth study presented in chapter eight showed how it is possible to take the DIY-Material development further by performing a series of steps. With a robust material development and with the main sensorial qualities and first physical characteristics obtained, some streams from future application of the DIY-Material begin to emerge. This is precisely what Test Hypothesis (TH4) suggested: DIY-Materials can achieve a mature level of qualitative development, and it is possible to analyze them with standard methods to reveal qualitative data.
From the fourth study, it is possible to conclude that when designers deepen into the material development, they can achieve advanced levels of understanding and manipulating some properties and qualities of the material. From this study, it is also possible to conclude how DIY-Materials can be developed with different stakeholders encountering possible streams for application either in small-scale production, inside industry or within a particular community.
The study also revealed how designers could add incremental steps to the development of a material, particularly by addressing different issues and collaborating with different disciplines and stakeholders. Many STEM materials developments follow a standard procedure where research on performance is the main focus. In this research, it became visible how a designer can achieve important results in de-

veloping a material by focusing on other aspects (either performative or not). It is essential to find the right tests to perform as well as to involve the different stakeholders who can contribute actively in the development of the project.

The different studies produced during this dissertation in addition to the material samples and physical results are several elements enriching the DIY-Materials Theory. Chapter nine highlighted the different outcomes of the studies in a series of steps and dissemination ideas. A test of these steps confirms that the DIY-Materials theory could produce high-quality materials samples. For sure it is not the only one, and different designers that were subject of study in the exploratory phase worked on materials without following this theory. However, by following this theory, similar results can occur, and possible alternatives to standard STEM materials can emerge.

10.2. Original contribution to the research context

The convergence of the three theoretical backgrounds, together with the case analysis, the course setting, hypotheses formulation and testing with design students highlighted an original contribution to the field of materials. The doctoral research is showing how designers can stop being passive receivers of information regarding materials and engage in an active role to develop materials. Different to what scientist create in labs, nowadays designers do not control the molecular properties of materials searching for an intended performative solution, but instead create materials following other strong motivations and are performing interesting emerging materials experiences. By highlighting expressive-sensorial qualities and putting the materials at the beginning of the design project, a new generation of artifacts with an original language is appearing. Different from what is commonly seen by the current state of the industry, where the selection of materials resides at the final stages of the process, the DIY-Materials theory enables designers to communicate the desired intention starting from the material. With the aid of a material and through the manipulation of it, designers are no longer using materials for their projects; they are designing through the material.
If this phenomenon continues to grow, is expected that DIY-Materials can enable social practices to tackle specific problems of communities.

By allowing people to solve a particular need or desire by the use of a local material source available, communities will have the chance to innovate quickly, closing circles and reducing impact in the environment with total autonomy and without the influence of industrial materials spread throughout the world without considering cultural differences and behaviors. Although these topics remain outside the limits of this dissertation, it is important to highlight them in this section to propose possible future developments of this theory.

This research aimed to describe and define the phenomenon of self-production of materials. It is grounded in the development of a series of codes and categories inside a system of rules to organize information around this particular class of materials. The proposed theory is composed of a language that allows seeing everything that surrounds from an alternative perspective. Living in a world of matter, everything we can touch, smell, see, hear and taste build up our lives. After the industrial revolution, societies were shaped in the way the technological advancements evolved. However, there is an alternative point of view. There is another way to see the world. The DIY-Materials theory is an attempt to produce a system of rules and conventions to categorize the different sources available on the planet and the technologies to transform them. Different from traditional sciences and economic approaches, where extraction of natural resources, mass production and trade of goods around the globe are the driving force, the self-production of materials offers a series of alternative principles and methodologies able to guide a more autonomous and independent way to produce things. It helps to relief from the weight and responsibility to depend on the current dominant world economy. Promotes an alternative idea of smart use of resources, considering resource even elements that before weren`t even considered. This research proposes a sustainable and circular perspective which can promote new social innovations starting from the materials. Within, it is possible to view and understand the opportunities DIY-Materials offer when considered as a possible practice in the design domain.

10.3. Critical issues

The doctoral research has shown some critical issues of the DIY-Materials practice. On the one hand, by auto-producing a material, the designer has control of the entire process, and it can enhance its creations taking advantage of the qualities of the material. On the other hand, these materials need to be improved continuously if the goal is to reach a specific market. DIY-Materials can be scaled up if desired, but, they need to pass several characterizations and tunings before they can be used for an intended project. By doing so, they will be no longer considered DIY-Materials. Inside this research, some laboratory tests and initial characterizations were performed. However, like with any other material development, it takes time to mature the idea and satisfy the requirements of a particular application. It is not the intention of this research to overcome traditional methods of STEM materials development. It is an alternative that can produce significant results in local realities and small-scale projects. Replacing other materials which are currently being used unproperly and generating negative social and ecological impact inside modern societies is one of the unaddressed goals of this research. To validate such hypotheses, in-depth studies in those directions must be performed in the future.

The goal of this research was to provide more insights into the phenomenon of DIY-Materials, by creating a theoretical framework for reference with a series of steps to develop a material form an experimental design approach. It is not the only one, and the characterization of this phenomenon into kingdoms may not be accepted, especially by traditional sciences which may not believe such approach can be compared with the natural classification of elements on earth. Still, this research aimed to understand better the emerging phenomenon and give an order to it for a better understanding inside the design domain.

The presented research may be considered pro DIY-Materials, and it indeed is. The lack of literature and studies on the area opened an opportunity. The research needs to be improved, and different scholars should carefully examine the categorization and subcategorization. This will allow to tune it better and make it more comprehensible by other areas of knowledge.

The performed studies inside this doctoral research were conducted inside an academic environment and under controlled environments. This provided incredible insights, but there is still an urgency to perform similar studies outside of academia. The real power of the DIY-Materials come when they are embedded inside a design project. Design professionals, material activists and design experts inside communities must take this theory and experiment with it. Only then it will be possible to understand if whatever is being placed in the market with this DIY-Materials approach, can undoubtedly improve society and generate balance to the traditional ways of developing materials.

10.4. Valorisation of the research

The different outcomes of this research have been presented in different conferences and are published in journals as articles. In some lectures and participation to events was possible also ti evidence the research and disseminate the work.

10.4.1 Journal Articles

- Rognoli, V., **Ayala-Garcia, C.** (2018). Materia emocional. Los materiales en nuestra relación emocional con los objetos. In: Revista Chilena de Diseño, rchd: creación y pensamiento, vol. 3 (4), pp.1-12. ISSN:0719-837X
(available at: https://rchd.uchile.cl/index.php/RChDCP/issue/view/4894)

- **Ayala-Garcia, C.**, Rognoli V. (2017). The new materials aesthetics. DIY Materials as triggers of new sensorial experiences. In: The Design Journal, volume 20, 2017 - Issue sup1: Design for Next: Proceedings of the 12th European Academy of Design Conference, Sapienza University of Rome, 12-14 April 2017, edited by Loredana Di Lucchio, Lorenzo Imbesi, Paul Atkinson, ISBN 978-1-138-09023-1, pp. S375-S389
(available at: http://www.tandfonline.com/doi/abs/10.1080/14606925.2017.1352905) (Scopus)

- Rognoli, V., **Ayala-Garcia, C.** (2017). Materials activism. In: Cuadernos del Centro de Estudios de Diseño y Comunicación, Universidad de Palermo, Buenos Aires, Argentina. ISSN: 1668-0227

- Rognoli, V., **Ayala-Garcia, C.**, Parisi, S. (2016). The material experiences as DIY-Materials: Self production of wool filled starch based composite (NeWool). In: Making Futures Journal, vol. IV, ISSN 2042-1664
(available at: http://makingfutures.plymouthart.ac.uk/journal-home/)

10.4.2. Conference papers

-Zhou, Z., Rognoli, V., **Ayala-Garcia, C.** (2018). Educating designers through Materials Club. In:

Proceedings of the 4th International Conference on Higher Education Advances (HEAd'18). Valencia, Spain, June 2018 - ISBN:978-84-9048-690-0

-Parisi, S., Spallazzo, D., Ferraro, V., Ferrara, M., Ceconello, M., **Ayala-Garcia, C.**, Rognoli, V. (2018). Mapping ICS Materials: Interactive, Connected, and Smart Materials. In: Karwowski, Waldemar, Ahram, Tareq (Eds.). Intelligent Human Systems Integration, Proceedings of the 1st International Conference on Intelligent Human Systems Integration (IHSI 2018): Integrating People and Intelligent Systems, January 7-9, 2018,
Dubai, United Arab Emirates, Volume 722 of the Advances in Intelligent Systems and Computing series, ISBN 978-3-319-73888-8. pp.1-7 (Scopus)

-**Ayala-Garcia, C.**, Rognoli, V., Karana, E. (2017). Five Kingdoms of DIY Materials for Design. In: Proceedings of EKSIG 17 - Alive. Active. Adaptive - Experiential Knowledge and Emerging Materials, 19-20 Jun, The Netherlands.

-Parisi, S., Rognoli, V., **Ayala-Garcia, C.** (2016). Designing Materials Experiences through passing of time. Material Driven Design Method applied to mycelium based composites. In: Proceedings of 10th International Conference on Design & Emotion, Amsterdam, The Netherlands, September 2016. Pp. 239-255. (Scopus)

-Rognoli, V., **Ayala-Garcia, C.**, Parisi, S., (2016). The emotional value of Do-it-yourself materials. In: Proceedings of 10th International Conference on Design & Emotion, Amsterdam, The Netherlands, September 2016. Pp. 233-241. (Scopus)

10.4.3. Events and lectures

- Rognoli, V., **Ayala-Garcia, C.** (2018. September). Materials education and DIY-Materials. Presented at: RISD Rhode Island School of Design. Rhode Island, United States.

- Rognoli, V., **Ayala-Garcia, C.** (2018. September). DIY-Materials approach to materials for design. Presented at: MIT Media Lab - Object-Based Media Group. Cambridge, United States.

-Karana, E., Rognoli, V., **Ayala-Garcia, C.**, Parisi, S., Barati, B, Petreca, B. (2018. June). The DIY-Materials and the city - Workshop: mine the city lab: Matterathon - June 2018, Border Sessions, Tech Culture Festival. Den Hague, The Netherlands.
https://www.bordersessions.org/lab/mine-the-city-lab-matterathon-day-2/

- Rognoli, V., **Ayala-Garcia, C.**, Parisi, S., Ferrara, M. Pollini, B. (2017. December). DIY-Materials on Tour. The expressive-sensorial qualities of self-produced bioplastics - Workshop at the Creative Marathon 2017, Elisava, School of Design and Engineering. Barcelona, Spain.

- **Ayala-Garcia, C.,** Parisi, S. (2017. October). DIY-Materials on Tour. Workshop at the ZHdK, Züricher Hochschule der Kunst. Zürich, Switzerland.

-**Ayala-Garcia, C.** (2017. June). DIY-Materials Research. Presented at: The Materials Farm Inspirational Talks. Materfad+Elisava Fad Fest'17, Barcelona, Spain.
http://fadfest.cat/website/materials-farm-inspirational-talks/?lang=en

-**Ayala-Garcia, C.** (2017. May). The Materials Generation. at: Pensiero e Progetto, I grandi contemporanei e le cose del design. Alma Mater Studiorum, University of Bologna. Bologna, Italy.

- Rognoli, V., **Ayala-Garcia, C**. (2018. April). Getting Inspired by Materials - Materials Selection from a Designer's Perspective. Presented at: 9th International Materials Education Symposium-University of Cambridge. Cambridge, United Kingdom.
https://www.materials-education.com/2017/cambridge/program.htm

- **Ayala-Garcia, C**., Rognoli, V. (2018. April). DIY materials approach for materials education in product design. Presented at: 9th International Materials Education Symposium-University of Cambridge. Cambridge, United Kingdom.
https://www.materials-education.com/2017/cambridge/program.htm

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3.4. Stile Industria Magazine from 1956 dedicated to the aesthetics of plastic materials. — Camilo Ayala Garcia.

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4.12. From top right, clockwise
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(b) From Insects by Marlene Huissod.
(c) Biocouture by Susan Lee. Camilo Ayala Garcia.

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(b) Coleoptera by Aagje Hoekstra.
(c) The Chicken Project by Kieren Jones. Camilo Ayala Garcia.

4.14. From top right, clockwise
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(c) Newool by Giada Lagorio.
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(d) Stratum by Jongjin Park. Camilo Ayala Garcia.

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(c) Structural Skin by Jorge Penadés.
(d) Stone Cycling by Tom van Soest. Camilo Ayala Garcia.

4.22. Bottom left (a) Precious Plastic by Dave Hakkens.
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(b) Mx3D by Joris Laarman.
(c) Green by Sebastian Straatsma. Camilo Ayala Garcia.

4.24. From left, counter clockwise
(a) Enactive Materials by Karmen Franinović.
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5.3. Driving sources examples in order from top left
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(b) Precious plastic seeks to tackle the wicked problem of
polymers garbage. Dave Hakkens.

(c) Bloodbricks seeks to build construction materials where is difficult to obtain bricks. | Jack Munroe.
(d) Sugru found an opportunity to fix and make products last longer. | Jane Ní Dhulchaointigh.
(e) Made by bees search unique production methods by co-creating with insects. | Tomas Libertiny.
(f) The new age of trichology, search aesthetics of human hair. | Sanne Visser.

5.4. Inspirational sources examples in order from top left
(a) Coleoptera inspires from a material concept by using dead parts of insects. | Aagje Hoekstra.
(b) Transcience X gets inspired by the colors of oxidation. | Lex Pott.
(c) Biocouture receives inspiration from bacteria to produce garments. | Suzanne Lee.
(d) Blueware Vases gets inspiration from traditional analog photography. | Studio Glithero.
(e) MX3D Gets inspiration from automotive welding robots and their movement. | Joris Laarman.
5.5. Technology sources examples in order from top left
(a) Improvisation Machine DIY rotational molding. | Annika Frye.
(b) The Growing Lab works in a lab to obtain mycelium. | Maurizio Montalti.
(c) FiDU developed a blow molding technology. | Oskar Zieta.
(d) Stone spray Hacked a 3D printer to inject sand. | Kulik, Shergill & Novikov.
(e) KIVI used traditional RAM compression method for ceramics. | Erin Turkoglu.

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5.12. (b) All cases from Kingdom Vegetabile evaluated and overlapped. Camilo Ayala Garcia.

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6.5. Material board for Kingdom Vegetabile. Camilo Ayala Garcia.

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6.7. Material board for Kingdom Animale. Camilo Ayala Garcia.

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6.11. Material board for Kingdom Recuperavit.	Camilo Ayala Garcia.
6.12. Aesthetical Attributes of Kingdom Recuperavit.	Camilo Ayala Garcia.
6.13. Material board for Kingdom Mutantis.	Camilo Ayala Garcia.
6.14. Aesthetical Attributes of Kingdom Mutantis.	Camilo Ayala Garcia.
7.1. Concept design studio course examples.	Stefano Parisi.
7.2. Design, materials and processes course examples.	Stefano Parisi.
7.3. Material Dynamism.	Giulio Masotti Susanna Todeschini Stefano Baruffaldi
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7.5. Materials experience.	Eunhee Jo.
7.6. Material driven design.	Dave Hakkens.
7.7. Materials tinkering.	Ioanna Oikonomou. Yudan Yang. Marta Ziminska. Marina Psimikaki
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7.9. Materials tinkering stage.	Esra Erdogan. Claudia Fumagalli. Clémence Paillieux. Yiu Hasegawa.
7.10. Evolution of materials stage.	Camilo Ayala Garcia.
7.11. Material storytelling stage.	Helga Aversa Aysecan Ertin. Muyun Wang. Simona Bettoni.

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	Ziyu Zhou. Nargess Shabani
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8.7. Weight loss data of Poli.Frutta obtained in the characterization phase.	Camilo Ayala Garcia. Ilaria Giani.
8.8. Apparent density data of Poli.Frutta obtained in the characterization phase.	Camilo Ayala Garcia. Ilaria Giani.
8.9. Graphic plot of the of Poli.Frutta tensile testing during characterization phase.	Camilo Ayala Garcia. Ilaria Giani.
8.10. Tensile tests data of Poli.Frutta obtained in the characterization phase.	Camilo Ayala Garcia. Ilaria Giani.
8.11. Sensorial evaluation data of Poli.Frutta obtained in the characterization phase.	Camilo Ayala Garcia. Ilaria Giani.
8.12. The Fabric Project Material Board.	Camilo Ayala Garcia.
8.13. Development of the Fluff material.	Valentina Maino.
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8.17. Sensorial evaluation data of The Fabric material obtained in the characterization phase.	Camilo Ayala Garcia. Valentina Maino.
8.18. The Fluff Material Board.	Camilo Ayala Garcia.
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8.21. Sensorial scales developed for The Fluff Project.	Valeria Munda.
8.22. Different samples developed for the CMF sensorial Atlas of Fluff.	Valeria Munda.

8.23. The Atlas of Fluff to develop expressive-sensorial characterization of the material.	Valeria Munda.
8.24. Sensorial evaluation data of The Fabric material obtained in the characterization phase.	Camilo Ayala Garcia. Valeria Munda.
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8.27. Graphic plot of the characterization phase.	Camilo Ayala Garcia. Dario Panico.
8.28. Pinearex showing all incremental steps from top to bottom: (a) Characterization of the material. (b-c-d) Manufacturing tests. (e-f) CMF development.	Dario Panico.
8.29. Life cycle simulation of the Pinearex material.	Camilo Ayala Garcia.
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8.34. Sensorial evaluation data of DIY-Cornstalk material obtained in the characterization phase.	Camilo Ayala Garcia. Karen Rodriguez.
8.35. Graphic plot and charts of the characterization phase. Above: (a) Density test. Middle: (b) Flexural strength test. Below: (c)Transversal tensile strength test.	Camilo Ayala Garcia. Karen Rodriguez.
8.36. Graphic plot and charts of the characterization phase. (d) Thermal conductivity.	Camilo Ayala Garcia. Karen Rodriguez.
8.37. Workshop with corn farmers in Colombia.	Karen Rodriguez.
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9.6. Example of Material Datasheets.	Helga Aversa. Aysecan Ertin. Muyun Wang. Simona Bettoni.
9.7. Example of Material Datasheets.	Mikaella Chrysosto- mou. Aysu Sani. Panayiota Vasile- iadou. Xiaodan Yang.
9.8. Examples of DIY-Materials diaries.	Fabrizio Guarrasi. Simona Bevere.
9.9. Example of a DIY-Materials video.	Chantal Mhanna. Giacomo Guaragna. Liqin Jin. Laura Guerrini.
9.10. Reference images for each step of the DIY-Materials Roadmap. See List of figures for image credits.	
9.10, 9.13, 9.16.	Helga Aversa.
9.11, 9.12.	Camilo Ayala Garcia.
9.14.	Esra Erdogan. Claudia Fumagalli. Clémence Paillieux. Yiu Hasegawa.
9.15.	Elvin Karana. Bahar Barati. Valentina Rognoli. Anouk Van der Laan.
9.17.	Dario Panico.
9.18.	Valeria Munda.

9.19.	Valentina Maino.
9.20.	Alexandra Bell. Angela Muñoz Carolin Winandi. Francesca Queirolo.
9.21. The DIY-Materials Roadmap schema.	Camilo Ayala Garcia.
9.22. Re-Surface Material Board.	Camilo Ayala Garcia.
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9.24. The DIY-Materials on tour during the Creative Marathon 2017, Elisava, School of Design and Engineering. Barcelona, Spain.	Stefano Parisi. Elisava.
9.25. The DIY-Materials exhibition inside the materioteca of Politecnico di Milano.	Camilo Ayala Garcia.
9.26. The DIY-Materials datasheets translated into the indexing and categorization system of the library at Politecnico di Milano.	Camilo Ayala Garcia.

Appendix 01

Case studied

Inside this appendix, it is possible to find all the different cases studied during this Ph.D. research. All images, recipes and other information were taken from the designer's website or an interview made by third parties. All information remained on the property of the designers and was taken to study and analysis for the proposed DIY-Materials Theory.

Kingdom Vegetabile

CS KVG 1-GIY - Ecovative
https://grow.bio/?ref=ecovativeshop

CS KVG 2 Algaemy - Blond and Bieber
http://blondandbieber.com/algaemy

CS KVG 3 Harvest Idée - Asif Khan
http://www.asif-khan.com/project/harvest-idee/

CS KVG 4 Autarchy - Formafantasma
http://www.designboom.com/design/formafantasma-autarchy/

CS KVG 5 Bacco - StudioNatural
http://www.studionatural.it/portfolio/bacco-foodmade/

CS KVG 6 Agar Plasticity - AMAM
http://www.kosuke-araki.com/#!blank-1/rb0s1

CS KVG 7 A Matter of Time - Stefano Parisi
http://blog.materfad.com/a-matter-of-time-stefano-parisi-seeds-2/

CS KVG 8 Myx - Jonas Edvard
http://jonasedvard.dk/work/myx/

CS KVG 9 Terroir - Jonas Edvard
http://jonasedvard.dk/work/terroir/

CS KVG 10 Flax Project - Christien Meindertsma
http://www.christienmeindertsma.com/index.php?/projects/flax-project/

CS KVG 11 Crafting Plastics - CPstudio
http://www.craftingplastics.com/studio

CS KVG 12 Artichair - Spyros Kizis
http://www.spyroskizis.com/

CS KVG 13 Shaping Sugar - Amelia Desnoyers
http://ameliadesnoyers.com/Shaping-Sugar-1

CS KGV 13 Sugar Glass - Fernando Laposse
http://www.fernandolaposse.com/projects/sugar-glass/

CS KVG 14 The Growing Lab - Officina Corpuscoli
http://www.corpuscoli.com/projects/the-growing-lab/

CS KVG 15 About a Pinetree - Sarmīte Poļakova
https://www.designacademy.nl/Study/Master/Studentprojects/tabid/2875/article-Type/ArticleView/articleId/2443/A-STORY-ABOUT-A-PINE-TREE.aspx

CS KVG 16 Unimaginary Project - Beatrice Cordara
http://cargocollective.com/beatricecordara/The-Unimaginary-Project-pt-1

CS KVG 17 Algarum Natura - Officina Corpuscoli
http://www.corpuscoli.com/projects/de-algarum-natura/

CS KVG 18 Shou Sugi Ban - Zwarthout
https://www.architecturaldigest.com/story/shou-sugi-ban-black-waterproof-wood-furniture

CS KVG 19 Piñatex - Carmen Hijosa
https://www.cartierwomensinitiative.com/candidate/carmen-hijosa

CS KVG 20 SPF Sugar Protection Filter - Federica Dellisanti & Tinka Jongerius
https://vimeo.com/129532379

Kingdom Animale

CS KAN 1 Made by Bees - Tomas Libertiny
http://studiolibertiny.com/

CS KAN 2 The New Age of Trichology - Sanne Visser
http://www.sannevisser.com/

CS KAN 3 From Insects - Marlène Huissoud
http://www.marlene-huissoud.com/

CS KAN 4 Hair Highway - Studio Swine
http://www.designboom.com/design/studio-swine-hair-highway-07-01-2014/

CS KAN 5 Hidden Beauty - Studio Gutedort
http://www.gutedort.de/?page_id=42

CS KAN 6 Ruminant Bloom - Julia Lohmann
http://www.julialohmann.co.uk/work/gallery/ruminant-bloom/

CS KAN 7 Coleoptera - Aagje Hoekstra
http://www.aagjehoekstra.nl/coleoptera.php

CS KAN 8 Cooked Wool - Freyja Sewell
http://www.designboom.com/design/cooked-wool/

CS KAN 9 Biocouture - Suzanne Lee
http://www.launch.org/innovators/suzanne-lee

CS KAN 10 Grow a Roll - Stefan Schwabe
http://stschwabe.com/work/GrowingARoll/

CS KAN 11 Cook 2 Design - Giada Lagorio
http://giadalagorio.com/portfolio/cook2design/

CS KAN 12 The Spider Farm - Thomas Maincent
https://www.flickr.com/photos/z33be/6943814204/in/photostream/

CS KAN 13 Bioalloy - Micro'be'
http://www.medinart.eu/works/bioalloy/

CS KAN 14 Xylinum Cones - Jannis Hülsen
http://www.jannishuelsen.com/?/work/Xylinumcones/

CS KAN 15 BioElectric - Jeongwon Ji
https://makezine.com/2014/03/21/from-pest-to-bioplastic/

CS KAN 16 Leather Sun clocks - Lina Patsiou
http://www.dezeen.com/2014/07/22/lina-patsiou-leather-sunclocks-tanned-solarium/

CS KAN 17 Leather? - Amon Matsuo
http://www.designboom.com/project/leather-2/

CS KAN 18 Red ink - Evelien Crooy
http://www.dezeen.com/2013/11/01/ink-made-from-cochineal-insects-by-evelien-crooy/

CS KAN 19 The Chicken Projectby - Kieren Jones
http://www.dezeen.com/2012/03/22/the-chicken-project-by-kieren-jones/

CS KAN 20 Herringbone Objects - Phil Cuttance
http://www.philcuttance.com/

Kingdom Lapideum

CS KLP 1 Transience X Transnatural - Lex Pott
http://www.lexpott.nl/work/35-transience-x-transnatural.html

CS KLP 2 Memorabilia Factory - Bold Design
http://bold-design.fr/en/projects/memorabilia-factory-design-exquis/

CS KLP 3 Oxidation Aftermath - Handmade Industrials
http://www.handmadeindustrials.com/oxidation-aftermath

CS KLP 4 Salt - Roberto Tweraser
http://www.robertotweraser.com/#salt

CS KLP 5 Blueware Vases - Studio Glithero
http://www.glithero.com/blueware-vases

CS KLP 6 Dust Matter-s - Lucie Libotte
http://lucielibotte.com/

CS KLP 7 Balloon Bowls - Maarten De Ceulaer
http://maartendeceulaer.com/Balloon-Bowls-single-pieces

CS KLP 8 Improvisation Machine - Annika Frye
http://www.annikafrye.de/portfolio/improvisation-machine/

CS KLP 9 Marwoolus - Marco Guazzini
http://marcoguazzini.com/products/marwoolus-2/

CS KLP 10 Stone Spray - Kulik, Shergill, Novikov
http://www.designboom.com/design/stone-spray-robot-produces-architec-ture-from-soil/

CS KLP 11 Color Casting Concrete - Ungyion Iwamura
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Kingdom Recuperavit

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CS KRC 2 Decafé - Raul Lauri
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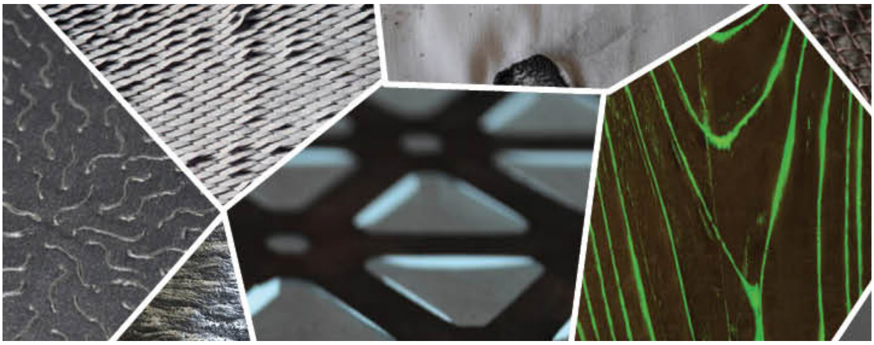

Kingdom Mutantis

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CS KMT 3 Magnetic Fabrics - Lilian Dedio
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CS KMT 11 Original Stool - BreadedEscalope
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CS KMT 20 Generative Scarves - Convivial
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Appendix 02

DIY-Materials Development Level I

Inside this appendix, it is possible to find a brief description of the different materials produced by the participants of the third study presented in chapter seven.

Kingdom Vegetabile

Farmed Materials

GreeNet

Helga Aversa (Italy), Aysecan Ertin (Turkey), Muyun Wang (China), Simona Bettoni (Italy).

Is a material developed using celery fibers. The filament of the vegetable most of the time is unpleasant and is removed while cooking. Here the designers extract those fibers and let them dry. By twisting them like any other filament, the celery can be knitted, and with simple crochet hooks, two-dimensional and three-dimensional shapes arise.

Leek paper

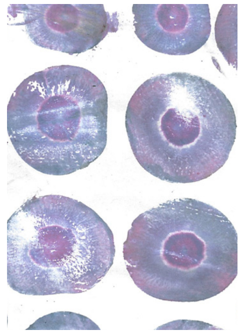
Esra Erdogan (Turkey), Claudia Fumagalli (Italy), Clémence Paillieux (France), Yiu Hasegawa (Japan).

Is a material obtained by peeling the surface layers of the leek. The designers found that the leek skin while wet is unable to absorb any ink. However, any crack on the material will retain the ink and migrate it through the direction of the fiber. This technique allows creating different colors patterns. The drying process of the leek sheets can take up to two weeks by pressing the inside a book or a notebook to obtain flat surfaces. Once dried it will reveal some cracks to add the ink.

Dacus Chromatic

Martina Kiselichka (Macedonia), Yaoyao Sun (China), Aleksandra Stosic (Italy), Wang Xingdi (China).

The material is ink and dye that comes from the extraction of the pigments, called anthocyanins, from the purple carrots.
Those pigments can change in structure, characterized by a shift in hue from red to purple to blue as the pH changes from acidic to basic in the medium in which the pigments are located. These features make Daucus Chromatic ideal for uses on paper and fabric.
With this material, the designers also wanted to spread the awareness of this less known ecotype of carrot, which has a long list of highly beneficial properties for our health.



Veggie paper

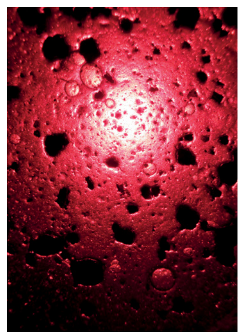
Mikaella Chrysostomou (Cyprus), Aysu Sani (Turkey), Panayiota Vasileiadou (Cyprus), Xiaodan Yang (China).

The cellulose ingredients and the fibers which compose vegetables are the main ingredients of these materials. Mainly fibers from banana, celery, and spinach. WIth the same techniques used to create DIY recycled paper, these designers obtained a homogeneous surface flat material. The interlaced non-woven fibers attached during the formation process providing a relative good structure to the paper. The designers addressed the project to tackle the problems that virgin papers create by turning down daily several thousand trees. By exploring with other vegetables and fruits which contain strong fibers, a balancing solution to the paper industry emerge.

Flexbeet

Leticia Melli (Brasil), Nitya Kumar (India), Mariana Ozaki (Brasil), Kaixin Fang (China).

Flexbeet derives from extracting the vibrant color of beetroot and combining it with corn flour. This flexible material is entirely natural as both the pigment and the base come out of organic ingredients.
The beetroot is a common ingredient of the Indian, Brazilian and Chinese cuisine, places of origin of the four members of this group.
This project reflects how the tinkering process of multicultural based groups could provide unique insights for the achievement of a DIY-Material.



Refruit

Ya Xiao (China), Lilach Pomerantz (Israel), Elena Sophia Di Giacinto (Italy).

Robust and flexible material with a different level of roughness on each side. Colorful patterns occur by using fruits with contrasting colors. The sustainable material feature comes thanks to the fact that it gives the fruit a second life after it has gone wrong or rotten. The mixture is spread on a silicone mat and patterns could be drawn with a squeeze bottle. After drying the material at sixty degrees Celsius for a period of up to eight hours, a blended flexible material comes out.

Ran

Hong Liang (China), Rocio Salinas Brotons (Spain), Wang Zhaoyu (China), Beatriz Ortigosa Gómez (Spain).

Ran is a kind of liquid material, used as a watercolor to paint on paper. It can also be mixed with other materials such as alum, Vaseline, etc., to apply in fabrics or over the skin. Children sometimes have to get in touch with synthetic pigments which is harmful to the environment and their health during painting. The designers intend to provide a set of dyes for mothers which they could self-produce in the kitchen using some onionskin, purple cabbage, banana peels, lettuce, pomegranate, baking soda, and vinegar obtaining a subtle color palette to use with their children.

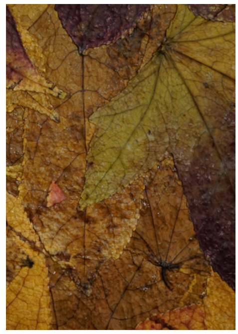
Agroleather

Cátia Filipa Rodrigues Ferraz (Portugal), Hajra Shamin Zuberi (Turkey).

It is a material which resembles leather with the new feature or possibility to be translucent. It can substitute leather or even rubber in some applications and is easy to produce, tackling problems such as animal abuse and excessive plastic production. Using agar, which is an element obtained by boiling red algae, adding some spices, sugar, and glycerine, this flexible DIY-Material presents itself as a cheap and locally available material.

Wild Findings

Catching Autumn



Cemal Çağlar Bektaş (Turkey), Lucia Kettl (Austria), Zeynep Ozge Aydin (Turkey), Magdalena Milly (Austria).
The creation of this material comes from the inspiration of fallen leaves and the desire to find a way to last autumn longer. Combination of different types of leaves in different colors offers endless possibilities for patterns. Wax finishing maintains the color of leaves same as they fell from trees.
Among its features are its attractive look, various patterns, and natural colors. It has a pleasant smell. Thickness can be arranged during making process according to wish.

Materials That Grow

Scent of herbs

Nguyen Phuong Thao (Vietnam), Leo Taiariol (France), Yijia Guo (China), Ahmed Hassan (Egypt).
Is known by some, how some plants contain phytochemicals that have effects on the body. After the team's research of herbs, they found a wide range of impact of herbs' scent that is beneficial to the human wellbeing. The designers create a series of samples of opaque or semi-translucent materials with several natural scents mixtures providing different healing effects improving physically, mentally or spiritually well-being.

EC Grass

Gabriele Milanese (Italy), Gunita Kagaine (Latvia), Hyeonju Park (Korea), Marco Jimenez (Mexico).
The grass is one universal and diffused graminoid plants humans use to cover the ground in almost every place. It grows in different heights and is trimmed regularly to maintain a uniform size depending on the use. Once cut, the material becomes a resource which can be used further before giving it back to earth. The designers proposed a series of material samples made of pure grass creating light, matte structures in different heights, forms and density depending on the length of fibers used.

Cover Skins, Peels and Natural Packages

Pomelo Skin

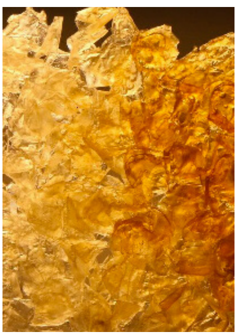
Vanessa Pascarelli (Italy), Elena Kyriakou (Cyprus), Alice Massari (Italy).
The designers developed a series of material samples made exclusively from pomelo's interior slice skin, which is an element that is not regularly consumed by people when eating the fruit. Dried pomelo skin has a particular behavior, being translucent when hit by light. The interior skin is a fragile material which can change shape thanks to heat and steam when ironed. When dried it loses its smell.

Peel it off

Tine Meert (Belgium), Caterina Rossato (Italy), Mathilda Sörvik (Sweeden), Qi Gao (China).
This project aims to give value to fruit peels. Instead of throwing them in the garbage, the designers propose a collection of materials to build at home very quickly. Using skins and adding water and flour, one can create a soft and malleable dough that hardens when is cooked in the oven or is left to dry in the air. Colored with spinach leaves, beetroot or wine, the materials can become a replacement for the different ones used in the creation of disposable objects which populates our home. Depending on the application, one can decide the thickness and give the shape before drying or cooking.

Kingdom Animale

Animal Remains



Sea snow

Divya Tahlani (India), Shan Pengcheng (China), Athulya Pillai (India), Yang Yucheng (China).
The material is made from fish scales. The fish scales are part of the fish skin and made of the protein collagen. As is not edible by humans the fish scale is removed from the surface of the animal skin either after fishing or before cooking the fish. The designers realize that just walking around the different Chinese restaurants of the metropolitan area of Milan, hundreds of fish scales were available for a second life. On the boiling process of the scales, the collagen gives rise to a resin-like material with excellent textural quality. The designers combined the fish scales with an Indian spice called turmeric achieving a gradient of color in mass. It has a semi-translucent appearance.

Porcaria

Gabriela Machado da Silva Lima (Brazil), Liping Ren (China), Luisa Hiromi Yatsu Simon (Brazil), Zheng Manlin (China).
The material is developed to change pigskin's properties and appearance, aiming to eliminate people's prejudice against it.
To begin is necessary to remove the fat of the skin and boil it until it's entirely "clean" and soft. Then process the skin with a mixer or a blender while it's still hot until it becomes a homogeneous liquid mass. By its nature, the pigskin by itself is elastic enough to make a plastic-like material. Nevertheless, the designers realized when adding the glycerin, as the plasticizer element, how the material becomes more flexible and harder to break. Adding pigments makes the material similar to synthetic silicones.

Animal Production

It's never too lat(t)e

Dicle Aslan (Turkey), Dinullah Bayu Ibrahim (Indonesia), Yizhuo Shao (China), Betül Ünal (Turkey).
The main ingredient is the expired milk. After milk is cooked with cornstarch, vinegar, glycerol, it can be formed with the desired shape and texture by using various surfaces. While it dries, the material naturally curves depending on the method. Either by drying in an open area or a closed environment with the help of a heater. With both ways, the final material becomes very strong and hard. In the phase of drying the shape could also be changed by cutting slices or creating a particular shape. The material is ready for its second lifecycle with the new form after dries.

Deconstruction of milk

Joohyun Kang (China), Kaiyu Wang(China), Shuang He(China), Yuko Iba (China).
The main ingredient in this project is the expired milk as well. Different from the previous one here the designers added lemon and salt to make the material rigid. By doing so, the milk loses its color and gain the color of the mixture. By leaving the samples on the oven with different periods, but at the same temperature, an interesting chromatic scale occurs.

Gelawool

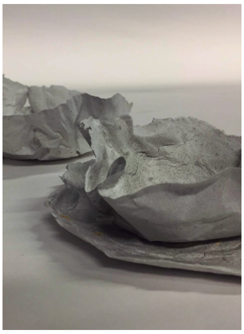
Alexandra Bell (Australia), Angela Muñoz Correa (Colombia), Carolin Winandi (Germany), Francesca Queirolo (Chile).

It is a flexible non-stretch material. It has a smooth surface while also giving the illusion of a wool texture. It can be molded into different shapes and thicknesses. "Gelawool" can be created using a gelatin mixture, combined with any wool. These samples contain Alpaca wool.

The material offers a mouldable illusion of a wool texture and can utilize designated wool offcuts and waste. Brushing through the alpaca wool to separate strands is easy to obtain the fibers needed to create the material.

Kingdom Lapideum

Low Crafted Ceramics



Breaknetic

Marianna Chacon Osojca (Colombia), Vanessa Petrucci (Italy), Markellos Polydorou (Greece), Didem Toker (Turkey).

Breaknetic is an interactive material based on the magnetic field that permits to recreate surfaces that interact with themselves. It is mainly composed of concrete with the addition of iron powder, a standard production leftover that allows the material to become magnetic. The main characteristic of this material occurs when it breaks. Thanks to the fabric element inside, it will enable all parts to stay together, but at the same time, it allows for interactions with other materials.

Plaster?

Maria Pekova (Bulgaria), Goktug Tanriverdi (Turkey), Evgeniia Shakleina (Russia).

The primary ingredient source chosen inside this team was the gypsum plaster which is extensively used for architecture and arts. After tinkering with different mixtures, the group obtained a mix of plaster and wax that allow producing uniform and stable shapes. Color is added to the mixture producing an interesting subtle palette. One of the main features is the different shades and textures that appear on the surface of each material sample when dried.

Growing plaster
No project

The Other Minerals

Melach

Dajana Grubisič (Serbia), Nastaran Nikaein (Iran), Ziyu Zhou (China), Nargess Shabani (Iran).
Sea salt is the main ingredient. Sand is used as a color additive and white rice as a binder. Different types of salt were used (their color and size vary depending on their origin) as well as several kinds of sand were used to obtain different colors and textures. As far back as 6050 BC, salt has been an essential and integral part of the world's history, as it blends into countless civilizations. By the time humans developed language skills, the use of salt with food was already commonplace. For this very reason, salt can be regarded as the substance of equal importance for all people on earth, whose unique aesthetic and taste are identifiable in any part of the world, regardless of linguistic, social, religious or cultural differences. Hence, the salt represents the basis for the design of the new material, whose distinctive features have led to the development of a material experience linked to the concept of universal language embodied in the material which is manifested in its natural, imperfect aesthetics as well as in the quite simple and low tech manufacturing process.

Nabatea

Mónica Pérez (Spain), Diana Gómez (Colombia), Reyes Romero (Spain).
Nabatea is a material that seeks to change the current perception of concrete. Adding 50% of pink Himalayan salt, the designers found a colorful mixture that could become a replacement for traditional concrete applications probably outside architectural and structural domains. This type of salt is believed to be one of the purest salts on the planet, and it gives aesthetic value to the product thanks to its pink color (a result of the variety of trace minerals that it contains). It is also the base of the trading economy of many communities in Pakistan. Nevertheless, it is a material product of mining activity, so to get a more sustainable concrete artificially colored sea salt could also replace this salt.

Salt sheets

Rana Talithashani (Indonesia), Yuan Cui (China), Ittikom Chanalithichai (Thailand), Sibei Chen (China).

Salt sheets are a new solution to upcycle used baking paper transforming it into a textured paper. A mixture of salt, wine baking soda, and water, the gets spread into the baking paper. Put back in the oven and heating all elements, the final result is a texturized paper with a pleasant look and touch, difficult to obtain with industrial methods.

Makeup saver

Valeria Rivera (Peru), Yuhui Li (China), Melos Zhita (Kosovo), Fei Yang (China).

Eyeshadows, Bronzers, and Blushes are everyday products used by millions of women daily to enhance their features. These products enter a cycle of disuse when they age, loose color or brake as a consequence of is fragility. As the majority of these cosmetics are made out of different minerals, bound with wax and oils, they tend to be insoluble in water and difficult to discard for recycling. This team of designers after different experimentations and tinkering phases have developed a possible alternative to these old cosmetics. As they are colorful and shining, they can be transformed into tiles of different sizes and shapes. By doing so, either with the aid of resins or without it, it is possible to have several kinds of semi-finished materials for different uses.

Kingdom Recuperavit

Recuperating Food Sources

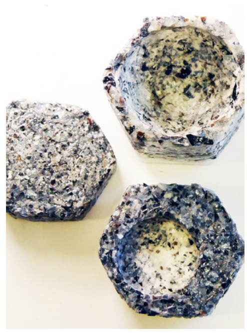
Fruit Concrete

Qianhui Gao (China), Magdalena Bober (Poland), Yujia Liang (China), Junyang Wan (China).

Raw, robust and stable material with a slightly glossy surface. It gets different colors and scent features according to the type of food source used to create the mixture. The material is developed to tackle excessive food waste. In many countries, especially in China and Italy, tea and coffee play a significant role in people's everyday life. People can daily consume thousands of tons of tea and coffee. Additionally, expired food and littered fruits can affect the environment badly if they are not disposed of properly. Using wax as a natural binding element, and taking advantage of density precipitation and gravity, the layered effect of the material creates an interesting visual and tactile language.

Habitat

Chia Hua Li (China), Qinyue Zhu (China), Sierra Yilmaz (Turkey), Yimu Yang (China).



A material intended to recuperate mussel shells. Mussels are used for different dishes especially in Italy. The amount of shells discarded daily in a restaurant represents an enormous organic waste. Mussels shells are fragile, and many tend to break during preparation and consumption. Therefore it is difficult to retrieve them in their original form. From the aesthetic point of view, these sources, have a fascinating iridescent color. By smashing the collected shells in different grain sizes, and arrange them in different directions it is possible to obtain different surface layouts and contrasts. Adding some vinegar to add more brightness to the shells, they can be inserted in a bio-based resin matrix to obtain a composite. The shells acting as a reinforcement, and depending on the arrangement can reflect light in many ways producing alternatives to different industrial materials.

C shells

Kari Ramstad Fjeld (Norway), Dong Shuran (China), Asa Albaz (Israel), Jiang Kaili (China).

Eggshells are, as we saw in the previous chapter, a considerable number of organic leftovers especially common from bakeries and restaurants. These shells can have a second life and be used for different purposes if we take into account the volume of production of this resource in a single day. This team proposes a stable material with a particular shape and texture. The eggshells are attached to a membrane that could be easily removed by boiling. Once clean, adding corn flour and vinegar it is possible to obtain a particular material which resembles coral from the sea.

Agrumiscela

Isabel Román (Spain), Qianni Chen (China), Beatriz Torre (Spain), Danfeng Gu (China).

A colorful material, with an agreeable aroma of citrus fruits, created from light and malleable, dry and semi-translucent skin of the lime, lemon, clementine, pomelo and bergamotto fruits. This material borns from the idea of analyzing the consumption of citrus fruits in the Mediterranean area, where hundreds of peels and fruit skins are daily discarded. By keeping their main characteristics, smell and color, the designers sewed the different skins creating different patterns contrasting and arranging the different skins of the fruits.

Shellboard

Maria Matilda Hagman (Sweden), Yi Wu (China), Li Xia (Taiwan), Anna Tornvall (Sweden).

Shellboard is a material obtained by chopping, mixing and binding different organic leftovers from food. During the cooking process, it is normal to fill a bowl with skins and peels of fruits and vegetables, eggshells, roots, and leaves. Adding organic binders such as starch, water, and vinegar the designers obtained a compound that could be compressed and shaped in different ways. This project aims to highlight the potential that daily leftovers can have when seen as resources. This bio-compound material could replace hundreds of plastic short live elements inside our domestic environments.

Eggsperience

Nick van Uum (The Netherlands), Cansu Cihaner (Turkey), Kasia Bragiel (Poland), Fangyi Chen (China).

Eggsperience, another material based on eggshells as the primary source, in addition to the driver of recuperating such enormous leftover from the food industry, it differs from the other projects as it adds to the mixture, edible ink, a common ingredient in the pastry. This ink, which comes in colorful and bright colors, add to the mix a lively and energetic appearance. Another feature of this material is the addition of gelatin to the matrix. The gelatin makes the whole composite more soft and flexible, providing coherence to the bright al cheerfulness of the surface appearance.

Recuperating Natural Sources

Funco
Claudia Catalani (Italy), Qinxia Chen (China), Martina Panza (Italy), Wenfei Yang (China).
A furry-like material which has a certain degree of flexibility. It comes from the cotton pads used to remove makeup from the skin. It is colored in different ways depending on the makeup color that it's taken off and it elicits different sensorial experiences. The usage of pads increases every year and is one of the disposable elements that sometimes aren't one hundred percent made from cotton, but from synthetic fibers, which can't be composted and have a longer decomposition time. Cotton pads are biodegradable, but still has a decomposition time of up to five months. Adding the makeup ingredients which are a mixture of minerals, oils, waxes, and pigments, it is difficult to compost correctly. In this project, the intention to reuse these elements which contain already dyes and lively colors could become an alternative to replace some other materials that require additional use of energy to gain color in mass before becoming a product.

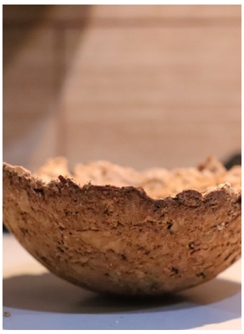
Recuperating Industrial Sources

Marbile
Ioanna Oikonomou (Greece), Yudan Yang (China), Marta Ziminska (Poland), Marina Psimikaki (Greece).
Marbile is a material made out of textile structures that looks hard and dense but is surprisingly soft, it has sufficient flexibility to bow under pressure, and will not shatter if dropped. Blending different cotton threads result in exciting color patterns that resemble natural stones. Tons of textile leftovers are produced every year. The textile industry accounts for one of the highest in water consumption while manufacturing. In the garments production chain, millions of textile pieces are thrown away and because of the uniformity of sizes cannot be reused by the same industry. The designers saw this as an opportunity to explore different ways to bring this waste to life while showing its beauty through another form. The team wanted to push the boundaries of 'waste' being perceived as 'cheap.' The material could be as precious as any stone but made sustainably.

Comprastic

Signe Lemche (Danemark), Nele Marie Kehmann (Germany), August Lund (Sweden), Tessa Hillen (The Netherlands).

Styrofoam is non-biodegradable and non-recyclable, it takes more than 500 years to decompose. In 2014 a total of 28,500 tons of Styrofoam was produced, and 90% was used to make single-use cups, trays, containers and packaging products. Every year we dispose of millions of tons of Styrofoam packaging which have an average use since the production of 60 days or less. Comprastic is a material proposal seeking to decrease the problem by transforming it into a useful source. By cutting and heating the Styrofoam, the material reduces its size to a minor density allowing it to compose into different shapes. The various pieces of material blend together with the aid of temperature.



Pizzaclay

Kübra Dilara Akbıyık (Turkey), Shen Ao (China), Filippo Baccolini (Italy), Jia Miao (China).

Pizza is one of the more eaten dishes of our modern world, according to the ISTAT, 17% of the restaurants in the world, serve pizza daily. Either as take away or for delivery, the amount of pizza that is transported in cardboard every week ascend to the billion units. The cardboard that transport pizza, different from the ones used for packaging goods, absorb oils and leaked sauces of the pizza, making it second class when it comes to recycling. This team of designers has developed an alternative to tackle this issue. By chopping the pizza box, mixing it with citrus, vinegar, and water, they produce a material that is compact, stable and light. The tinkering process was guided by the idea to remove above all the unpleasant smell of the leftover food impregnated in the cardboard. Therefore, the final result apart from the physical qualities, present a neutral aroma.

Silicork

Doaa Mohamed Reefat (Egypt), Martin Andreev (Bulgaria), Merve Kurt (Turkey), Susana Soto (Peru).

In Italy, the world bank shows that the population in 2016 reached 60.6 Million. As for the consumption of cork goes up to 34.1 liters of wine per capita, ranking as the 10th country in the world in 2016 according to the Telegraph news. The annual Consumption of wine in liters is 2,040,000,000.

Cork is natural, renewable, recyclable and biodegradable. Also, it has an insulation property for heat (R-value of 1.125) and noise. Also, it can be granulated and reused in other products. The students calculated that according to the statistics retrieved, an average of almost twenty-five million tons of cork could be produced by consuming wine in Italy. If we consider this amount, we can quickly gather enough material from home just by drinking a glass of wine per meal. With this consideration in mind, the designers have created a material out of cork and silicone, with good insulation qualities, water, and shock absorbent.

Cordeplastica

Akito Fukugi (Japan), Mingshan chen (China), Keith Pereira (India), Ce Guo China).
Low-density Polyethylene bags are still in use by many. Polyethylenes are the most used plastics worldwide as they have fantastic qualities but sadly sometimes are not applied to the right products. LDPE is fully recyclable like any other thermoplastic by the use of heat. However, other alternatives can be considered when there is no heat control for the recycling process. This team of designers has experimented with the different bags collected around in the market, by cutting them into stripes and sorting them by color. The mixed strips are braided together building small ropes of plastic.

Recuperating Common Waste

Tea Cycle

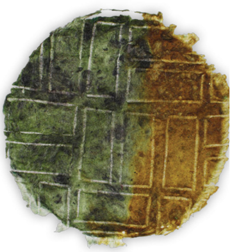
Xanthe Murphy (Australia), Lauren Nicholson (England), Karen Ratering (The Netherlands), Madeline Scully (Australia).
As of 2014, the team's combined home nations of Australia, the UK and the Netherlands consumption of tea was 4.01kg per capita (1). Putting this into perspective, one tea bag or one serving of loose leaf tea is just 2g- meaning that every resident of these three countries is responsible for over 2,000 cups of tea ending on the compost heap. However, the industry-wide practice of using polypropylene in tea bags makes them only 70-80% biodegradable (2), leaving fibers in the soil and causing damaging effects to the environment and trapping the tea inside so that it could not be composted (3).
The team wanted to find an innovative way to prevent used tea bags from being seen as a waste item. They developed three elements out of it. Inspired by ancient practices of compressing the loose tea they

developed tea bricks. By separating the teabags and binding them together with flour, they developed a tea card with particular features. Finally, the remaining tea together with water can produce inks of different colors.

Butts Bunny

Carolina Giorgiani (Italy), Jinan Jezzini (Romania), Davide Mosito (Italy).

A semi-translucent material with a certain degree of flexibility depending on the number of butts inside it. It can also be colored with different natural ingredients. The material aims to be a provocation for a different use of a huge problem: cigarette butts. Humans throw out 72 billion butts per year, and they represent, for example, 40% of waste in the Mediterranean Sea. The resulting material is a contrast between the beauty of it and the repulsion provoked to some people when acknowledging the raw material.



Fluff

Jusso Koski (Finnland), Valeria Munda (Italy), Eileen Kruger (Germany), Setareh Salehi (Iran).

Fluff is a material which is created by drying clothes in a dryer. Dry cleaners create significant amounts of dust every day, and it's usually just thrown in the trash without any consideration of reuse. Home used dryers, and lint removers also produce fluff. The team wanted to tackle this problem/opportunity by creating a new function for the waste "Invisible" material by enhancing its specific properties and adding new ones. While forming the material, the designers used natural ingredients so the ecological footprint would be as low as possible. Fluff is an elastic and semi-transparent material which can be colored and patterned in different ways depending on the wanted look. The material can also be created as a sturdy, solid material depending on the future application with different ingredients and ratios.

Midas

Tahmineh Setoodeh (Iran), Tina Jochens (Germany), Quentin Fedrizzi (France), Media Hosseini (Iran).

It's a light, opaque and fragile material. The smell of this material evokes particular remembrances of people's life. The material is developed to tackle one of the world's main problem, waste of cigarette on the streets. Around 4.5 trillion of the six trillion cigarettes smoked every year end up in the environment. It has been proved that "It only takes a single cigarette butt to contaminate a liter of water.". The team used the metaphor of King Midas to develop a whole concept to enhance a material source that is complex and difficult to threat, but at the same time it is highly contaminant and found for free in enormous quantities. Transforming such priceless material into a raw one, one can find a valuable resource.

Co

Shinpei Yokota (Japan), Wang Mengyao (China), Olga Musteata (Romania), Zhao Jiaxi (China),

Is a material created from burned discarded substances and wax. The diversity of ash grains together with the different amount of poured wax produce a considerable variety of samples. The contrast color and texture generated by the mix of the ash and the wax opens a new sensorial experience challenging to replicate with industrial materials. The team explored the different contrasts theories available to inspire the development of the different samples enhancing the sensorial experience.

Fifty shapes of ash

Dorota Balewicz (Poland), Hwansung Park (South Korea), Tessie van der Voort Maarschalk (The Netherlands).

Ash is a non-gaseous, non-liquid residue obtained after complete combustion. It is a lightweight, grey powder that consists mostly of oxides of calcium carbonate (25 to 45%), less than 10% potash and less than 1% phosphate. The darker the mixture is, the more charcoal it contains. The amount of ash from burning wood varies from 0,3% of the original weight up to 10%. The obtained amount depends on the temperature of burning, dry-mass contamination and the type and age of a tree.

Ash is a highly hygroscopic substance. It feels smooth but leaves hands dry and rough. It is alkaline, as a result of that ash is antibacterial. WHO recommends ash as a substitute to soap when soap is not available. Because it is rich in compounds such as lime and potassium, it can be added to compost or used merely as a fertilizer in the garden. By mixing it with Gypsum, starch, and water, the designers proposed a variety of samples in which the ash can express its qualities, sometimes behaving as a solid material, sometimes as a fragile one.

Kingdom Mutantis
Material Mutations

Cu Later

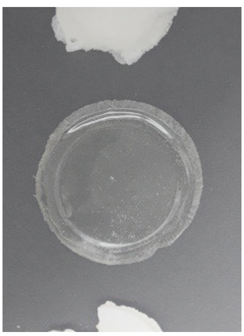
Chantal Mhanna (Lebanon), Giacomo Guaragna (Italy), Liqin Jin (China), Laura Guerrini (Italy).

Cu LATER is composed of white concrete and little particles of those changing-appearance metals that can be found as leftovers or waste of processing in workshops or factories. Oxidation over the surface of the concrete is the main feature of this material. The more metals and water, compared to the quantity of the concrete, the more the outcome showed the effects of the oxidation. The shrinkage and the time to fix the concrete increased. Strictly connected is the "time" factor. The experiments showed that the more the time passed, the more the effects on the materials surfaces became more visible. This behavior mainly depended on the quantity of water the concrete, and the metals absorb during the solidification and on the external, "environmental" factors that caused a variation in the material appearance. By exposing the final materials to humid environments or in direct contact with external weather conditions, the process of oxidization was sped up considerably.

Vague

Ruo Xu (China), Weijia Wang (China), Yuanchao Wang (China), Kaiyu Guo (China).

Vague is an attempt to reveal the hidden properties of paper. The designers transform paper into a different perceived material adding features such as transparency and gold-like dyes. The mutated paper becomes transparent by adding wax and oil, revealing hidden features and fiber arrangements. The designers added to the mixture some stains producing a material perceived as elegant and expensive due to the combination of elements and the layouts proposed by the team.



Vamoose

Raziyeh Gholamhosseinzadeh (Iran), Alena Konnova (Russia), Siyi Chun (China), Jimena Parra (Colombia).

Vamoose is a biodegradable material that can disappear under some chemical and environmental reactions. This combination of bioplastic and dust produces a material that could have a broad range of application, and that after is used, it suddenly disappears.

Thesis Work of third study

Poli.frutta

Development of a DIY Bioplastic Material as an alternative.
Ilaria Martina Giani (Italy).
Supervisor: Valentina Rognoli
Co-Supervisor: Camilo Ayala Garcia
Co-Supervisor: Claudia Marano

http://hdl.handle.net/10589/132984

The Fabric Project

Shaping an invisible material.
Valentina Maino (Italy).
Supervisor: Valentina Rognoli
Co-Supervisor: Camilo Ayala Garcia
Co-Supervisor: Stefano Parisi

http://hdl.handle.net/10589/138357

The Fluff Project

The Identity of an invisible material.
Valeria Munda (Italy).
Supervisor: Valentina Rognoli
Co-Supervisor: Camilo Ayala Garcia
Co-Supervisor: Stefano Parisi

http://hdl.handle.net/10589/138348

Pinearex

Pine cone based material.
Salvatore Dario Panico (Italy).
Supervisor: Valentina Rognoli
Co-Supervisor: Camilo Ayala Garcia
Co-Supervisor: Claudia Marano

http://hdl.handle.net/10589/138385

CornStalk DIY-Material

Do It Yourself Material for Social Innovation.

Karen Estefanía Rodríguez Daza (Colombia).
Supervisor: Valentina Rognoli
Co-Supervisor: Camilo Ayala Garcia

http://hdl.handle.net/10589/138370

Re-Surface

Upcycle Della Vetroresina Recuperate da Le Imbarcazioni

Helga Aversa (Italy).
Supervisor: Valentina Rognoli
Co-Supervisors: Carla Langella, Mario Malinconico, Andrea Ratti
Advisor: Camilo Ayala Garcia

http://hdl.handle.net/10589/142282

About the Author

Camilo Ayala Garcia was born in Bogotá (Colombia). Camilo joined Politecnico di Milano in November 2015 as a Ph.D. Candidate in Design in the XXXI Cycle. He belongs to the Materials Experience Lab, a Lab coordinated by Elvin Karana and Valentina Rognoli, which introduces unique ways of understanding and designing (with) materials by combining research methods, techniques, and tools from product design, social sciences, materials science, and engineering. Prior to this Ph.D. research, Camilo received his Bachelor degree in Industrial Design from the Los Andes University in Bogotá in the year 2004. He also obtained his Bachelor Degree in Textile Design from the same university simultaneously. In the year 2007, received his Master of Arts in Design degree from Domus Academy (the University of Wales accredited school of design) in Milan awarded with Distinction.

Camilo began his professional career at CD&I Associates Colombia back in 2001, where he earned experience in the product design field developing several projects for renowned local and international clients. After various years of work as a professional designer, he moved to Germany to attend at HS Pforzheim the MSc. Produktentwicklung (Product development) as a guest student and learn the language. Subsequently, he transferred to Italy to complete his Master studies. After his graduation, he started to share time being tutor at the Domus Academy and working as a product designer for Donegani & Lauda studio and Cammarata Gioelli both in Milan for a couple of years. Camilo decided to return to his hometown to become full-time professor and researcher at his alma mater where is currently entitled Assistant Professor in the design department. Together with his teaching activities, Camilo devotes his research to local materials and products development, with several patents granted as well as different academic contributions published.