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Experiential Characterization of Materials: toward a toolkit

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Traditionally in science and engineering, materials are characterized *technically*, through a series of studies aiming at probing and measuring the structure and properties of materials. In design, a holistic approach to materials is adopted which requires the characterization of materials for their experiential qualities, alongside the technical understanding. Despite the increasing attention to the notion of materials experience, design methodology lacks a systematic tool to support the experiential characterization of a material at hand. This paper presents the development of a toolkit to facilitate the *experiential characterization of materials*. The toolkit has been developed based on existing tools and approaches within the materials and design domain, and through two exploratory workshops conducted with design students and design professionals. The workshops provided useful insights to improve the toolkit's final design, which is presented in the paper. While the toolkit needs further adjustments and validation, the discussion highlights how this approach can support design practice in conducting materials characterization studies in diverse situations.

materials experience; characterization; materials; design tools

1 Introduction

Over the last decades, research has devoted increasing efforts to support a dualist understanding of materials, which *emphasizes the role of materials as being simultaneously technical and experiential* (see www.materialsexperiencelab.com; Karana, Pedgley & Rognoli, 2014; Ashby & Johnson, 2002; Miodownik, 2007). Traditionally in science and engineering, materials are characterized *technically*, through a series of studies aiming at probing and measuring the structure and properties of materials (Leng, 2009; Zhang, Li & Kumar, 2008; Ashby & Johnson, 2002). Thus, material characterization concerns *what a material is* and how it behaves under certain conditions (e.g. under compression or in contact with water). When it comes to materials in product design, experiences that materials elicit in user interactions are equally important to achieve a holistic understanding and inform the design process (Ashby & Johnson, 2002; Miodownik, 2007; Karana, Hekkert &

Kandachar, 2008). Such an understanding of materials does not only provide guidance on how people are likely to experience a particular material in future product applications and how to improve materials accordingly for commercial success (Karana, Pedgley & Rognoli, 2015), but it also inspires designers and material developers to come up with innovative material and product ideas (Karana et al., 2015; Wilkes et al., 2016). In other words, understanding material experiences can enrich designers' vocabulary and open up the design space for unique functions and expressions (Karana et al., 2015; Barati, Karana & Foole, 2017).

Karana et al. (2015) define this activity as the ***experiential characterization of materials***, which concerns investigating how a material is received, what it makes people think, feel and do. They emphasize that when the experiential qualities of a material are probed and mapped alongside the material's technical properties and performances, a thorough understanding of the material is achieved to guide the design process. Accordingly, the experiential characterization of materials should provide designers with an understanding of *what* people experience when they encounter a material (e.g. they find it 'surprising', or 'cozy'), *to what extent they agree with each other* (e.g. how many of them are 'fascinated' by the material), and *why* they experience a material in the way they do (e.g. what sensorial qualities of the material elicit 'surprise').

This understanding is particularly essential when materials are taken as departure points of the creative process, and are explored for their potential to evoke unique and meaningful product experience (Karana et al., 2015; Wilkes et al., 2016; Miodownik, 2007; Karana, Pedgley & Rognoli, 2014; Chen et al., 2009; Gransber et al., 2015; Light.Touch.Matters EU project, http://www.ltm.io.tudelft.nl/). However, design professionals often have limited time and skills to invest in user studies, which might usually take considerable time within a project timespan (Sanders, 2005). There is no single tool to date to support experiential understanding of a material in a systematic, holistic, yet *agile* way, thus facilitating the uptake of this practice. In this paper, we present our initial attempt toward the development of a tool to support design professionals and material developers in conducting a set of user studies to characterize materials experientially. In the next sections, we first present the notion of materials experience as a foundation for our tool. Then, we will elaborate on the existing tools developed over the last two decades to support designers in their experiential understanding of materials. We will then present the development of the tool through two iterations: first, the development and testing of a draft version, used in two workshops with design students and design professionals. Secondly, we describe the refinement of the tool towards its final version. In the discussion, we address possible uses and applications of the tool and identify future steps for the tool validation.

2 Understanding Materials Experience

Materials of products are acknowledged as one of the most effective sources to affect the experiences people have with and through products (Karana, 2009). While the experience of metal changes whether we encounter it in a sleek water bottle or in a gun, the opposite also stands true – a gun made of foam will be hardly as scary as a metal one. The term '*materials experience*' was first introduced by Karana et al. (2008) and elaborated in a recent framework by Giaccardi and Karana (2015), emphasizing the active role of materials in shaping the ways people interact and experience products at four experiential levels: (1) **sensorial level** (e.g. we think the material is heavy or rough), **(2) interpretive level** (e.g. we think it is modern or high-quality), (3) **affective level** (e.g. we feel fascinated or surprised by the material), (4) **performative level** (e.g. the material makes us tweak it or caress it). These levels articulate an *operational understanding of materials experience*, categorizing different experiential qualities that can be elicited by materials. Nevertheless, these levels of materials experience are highly intertwined and experienced as a whole, influenced by each other and by other factors such as time and context of use (Karana, Pedgley & Rognoli, 2014; Giaccardi & Karana, 2015). Hence, materials experiences can be quite challenging to study and research. It requires a delicate balance between studies that provide both a holistic perspective on

the overall experience and detailed, specific information that allows designers to understand how materials can be manipulated to fulfil a design intention. In the next section, we will overview the tools that have been developed to date to provide such an understanding of materials.

3 Tools for Understanding Materials Experience

In recent years, research has made increasing efforts to foster the inclusion of materials experience considerations in product design (Pedgley, 2014; Ashby & Johnson, 2002; Wilkes et al. 2016). These efforts led to the development of few tools that can help designers to explore, assess and manipulate the experiential qualities of materials. For example, Rognoli's Expressive-Sensorial Atlas (2010) was developed as a tool to deepen designers' knowledge about materials' experiential qualities. It consists of a collection of maps related to one or more properties (e.g. tactile experience map), which designers can use to rank and compare different materials. In this way, the tool invites designers to reflect upon the sensorial and expressive properties of materials. Van Kesteren (2008) devised four tools (the Question tool, the Picture tool, the Sample tool and the Relation tool) that consisted of checklists, visuals and vocabularies to stimulate designers in the consideration of materials' sensorial properties during the early phases of design. Zuo (2003) developed instead the Material-Aesthetics Database, describing materials textures based on four dimensions: geometrical (e.g. irregular- repetitive, plain- bumpy, etc.), physical-chemical (e.g. warm- cold, mist- dry, etc.), emotional (e.g. cheerful- dull, comfortable- uncomfortable, etc.), and associative dimension (feather-like, silky, etc.). The tool is meant as a database of research outcomes, generated through user studies, that designers can browse during materials selection, exploring the interrelationships between the experiential qualities on a matrix (Zuo, Jones & Hope, 2004). Similarly, Karana's (2009) Meanings of Materials Tool encourages designers to select materials based on their 'meaning evoking patterns', based on a dataset generated by empirical studies across different user groups. The tool has been tested in several case studies and projects (Karana, 2009; Karana, 2012).

Bang (2007) adapted the Repertory Grid technique to investigate users' emotional concerns to textiles. The approach combines the comparison of material triads by rating them on selected properties (e.g. hard vs soft); and qualitative methods to achieve deeper insights about user-material relationships (Petersen & Bang, 2016). Recently, Hasling (2016) developed a canvas to organize and distinguish different material qualities (e.g. associative and emotional) particularly to be used in design education.

The majority of these tools were developed to serve different purposes, e.g. for educational purposes (Rognoli, 2010; Hasling, 2016); or materials selection (Zuo, 2003; Karana, 2009), rather than to specifically support *active research* for the experiential characterization of materials. Their underlying logic can be used to structure materials experience studies, as demonstrated in a number of projects (see e.g. Karana, 2012; Lilley et al., 2016; Sauerwein, Karana & Rognoli, 2017; Howes et al., 2014; Salvia, Rognoli & Levi, 2013; Overvliet, Karana, & Soto-Faraco, 2016; Asbjørn Sörensen, Jagtap & Warell, 2017). However, the tools listed often focus on one level only (e.g. the sensorial, Sensotact® by Renault, Allione et al., 2012); and they ground on an earlier definition of materials experience (Karana, Pedgley & Rognoli, 2014), thus they do not cover the characterization of materials' performative qualities. Nevertheless, all these attempts share the following concerns to facilitate an experiential understanding of materials for design professionals: (1) it is important to provide information both on the material's experiential qualities, and on their interrelationships; (2) tools should provide the results of the study in an engaging and inspirational manner to support the creative process.

The way these tools have been applied demonstrate the variety of situations that materials experience studies entail. Sometimes, designers might want to compare the same material in different variants (e.g. more or less fibred; or different colors, see for example Karana, 2012); or to explore one specific material in comparison with other known materials (Bakker et al., 2015). In some other cases, designers might be interested in only specific aspects of materials experience, for

example the relationship between sensorial qualities and triggered actions (see for example Barati et al., 2017). Lastly, materials experience studies can be conducted in controlled environments such as a lab setting or a design studio; yet often times, designers engage with users' responses to materials during exhibitions or events (Camere & Karana, in press). Our goal is thus to facilitate the experiential characterization of materials in this variety of situations, and in relation to the four experiential levels (Giaccardi & Karana, 2015).

4 Designing a tool for designers

Design methods and tools are meant to assist designers in handling wicked problems (Buchanan, 1992) and uncertainty characterizing design problems and practice (Dorst, 2011), as effectively and efficiently as possible (Daalhuizen, 2014; Cross, 2006). Design tools aimed at supporting design practice should stimulate *reflection-in-action* (Schön, 1983; Stolterman et al., 2008), *externalization* of design ideas and *perception* of new facets of the design situation (Dalsgaard, 2017). They should be designed so that they are immediate to learn, precise and simple, and allowing a quick engagement with the design situation (Stolterman, 2008), without being prescriptive of design outcomes (Daalhuizen, 2014). Aspects such as how *flexible* the tool is, how much *freedom* it provides and how *easy* it is to use should be considered in the tool development to achieve its easy uptake (Stolterman & Pierce, 2012; Daalhuizen, 2014).

Moreover, design professionals often have limited time and skills to invest in user studies (e.g. performing statistical analysis from empirical data). For this reason, they tend to prefer qualitative and self-developed toolkits over structured and quantitative studies (Koskinen et al., 2011; Sanders, Brandt & Binder, 2010). To that end, the most important features of a tool to explore user experience is the stimulation of empathy (McDonagh & Denton, 1999; Mattelmäki, 2005) through the engagement with rich experience information that can provide inspiration for idea generation (Sleeswijk-Visser, 2009; Sanders, 2005). Accordingly, designers have shown preference toward visual and little text-based representations of such rich information (e.g. diagrams, graphics) over long, textual reports in both product and materials experience studies (Karana, Hekkert & Kandachar, 2010; van Kesteren, 2008). These requirements, together with the considerations on how materials experience can be investigated, outline the ingredients of a tool to support design professionals in the experiential characterization of materials.

5 [Ma2E4]: a tool for experiential characterization of materials

Based on this analysis, we conclude the subsequent objectives:

- The tool should provide both **specific (i.e. individual levels) and holistic (i.e. interrelationships between four levels)** information about materials experience, balancing rich, qualitative descriptions and targeted, comparable data.
- The tool should provide **structure** and **vocabulary** to collect, analyze and present data, without being prescriptive of design outcomes and solutions.
- The tool should be **agile**, **easy-to-learn** and **flexible,** to be adopted in different situations to support materials experience studies.
- The ultimate purpose of experiential characterization studies is to reveal new insights and facets of how materials can be manipulated to elicit novel and positive user experiences. The tool should support organizing and communicating results in a way that it will **inspire** designers toward such user experiences.

Accordingly, we set out to design a tool to meet the listed objectives. The tool is structured around the four levels of materials experience, i.e. sensorial, interpretive, affective and performative (Giaccardi & Karana, 2015). To balance holistic and specific information, the tool should provide information on the experiential qualities elicited by the material (e.g. 'rough' or 'smooth'), the

specific ***mode*** in which the quality is experienced (e.g. if a material is perceived as 'very rough' or 'mildly rough'), and the ***interrelationships*** why this experience is triggered (e.g. why do they think a material is 'natural' or 'surprising'). Table 1 shows what these three layers entail with regard to a material's experiential understanding.

Table 1. three layers in experiential characterization of materials.

	sensorial	interpretive	affective	performative
quality	rough	elegant	surprised	caressing
mode	very rough	elegant like a luxury palace	negatively surprised	gentle/repetitive caressing
relationships	the material is very surprising because it looks rough but feels very smooth.			

We name the tool as **Ma2E4**, acronym for *Materials-to-Experiences at four levels*. As it consists of a collection of tools, one for each experiential level, it will be referred as a *toolkit*.

For the ***sensorial*** level, the Ma2E4 toolkit includes the sensorial scale developed as part of Karana's (2009) Meanings of Materials tool, and later adapted in Sauerwein, Karana and Rognoli (2017). The list provides frequently used sensorial qualities (both by designers and end users to describe materials), which were empirically validated across different materials experience studies (Karana, 2009). Similarly, for the ***interpretive*** level, we adopt the list of 22 meanings commonly associated with materials (Karana, 2009). These meanings offer very broad interpretation and several distinct sub-meanings (e.g. a material can be handcrafted in the sense of exquisite refinement or in the sense of imperfection). In order to detail the specific understanding of the different sub-meanings, we rely on the use of pictures, which can help articulating the mode in which the meaning is experienced because of the unequivocalness of visual information (Govers, 2004).

As there is no specific vocabulary available in relation to the ***affective*** level of materials experience, we adopted the taxonomies from product experience for both positive (Desmet, 2012) and negative (Fokkinga, 2015) emotions elicited by products. These vocabularies provide comprehensive sets of descriptors (n=25 facets of positive experiences; n=22 negative emotions). To obtain a manageable list, and relate it more to materials affective experiences, we cross-matched the vocabularies with the set of descriptors found by Karana in an earlier study (Karana, Hekkert & Kandachar, 2008). In this way, we could select 20 emotions that were validated through systematic research (Desmet, 2012; Fokkinga, 2015) and that are also used in describing materials at the affective level (Karana, 2009). The list includes an equal number of emotions that are generally considered positive or negative; however, the real valence (i.e. the pleasantness of emotions) can largely depend on user's subjectivity (Russell, 2003). To detail the specific mode in which the material is experienced, we adopt Russell's model (2003), which explains emotions as characterized by the two main dimensions of arousal (i.e. intensity) and valence (pleasant vs. unpleasant). The four-axis diagram shown in Figure 1b will be used to rate whether the emotion is actually experienced as pleasant or unpleasant, and the intensity to which this state is perceived.

As we mentioned, no specific tool is available to characterize the ***performative qualities*** of materials. While we acknowledge the need of further studies on the topic, to give an initial idea we decided to include the performative materials exploration pictures provided by Karana et al. (2016), which describe different types of actions elicited by material-user interactions (Figure 2).

6 Toolkit development

The toolkit was developed through two iterations. In the first stage, a draft version (Version 1) was tested in two workshops, both with design students (workshop 1) and design professionals (workshop 2). These two workshops were aimed at testing the overall approach of the toolkit, its specific components (i.e. the tools included) and exploring the benefits and limitations with prospect users of the toolkit (i.e. design professionals, material developers and design students). We observed participants' usage of the toolkit through the workshops and discussed their experience with the toolkit at the end of the workshops. The sessions were also audio-recorded. Participants' comments were transcribed after each session and analyzed through content analysis (Krippendorff, 2004).

Figure 1. From left: a) The draft version of the Ma2E4 toolkit; b) card and maps included for the affective level.

6.1 Toolkit Version 1

The first draft of the Ma2E4 toolkit was designed as a box containing several envelopes, each addressing one activity for the experiential characterization of materials (Figure 1a). The envelopes provided *cards* with the instructions for the facilitator and *maps* to record how people act upon and describe a presented material (Figure 1b). Beside the four levels, the tool also included two more activities, one at the start and one at the end of the experiential test. The first activity was called *'free exploration'*, during which participants were given a material sample and asked to interact with it freely, while explaining their first impressions. The activity was meant to explore people's initial reactions without the influence of the provided vocabulary of the toolkit. After this, the facilitator could proceed with the 'study' focusing on the four sub-activities related to the four experiential levels. Lastly, the '*reflective close-up'* suggested showing participants a prototype demonstrating the material in a shape (Figure 1a). This phase was particularly meant for researchers to understand whether (or not) people's reactions change when they see the same material embodied in products. We suggest that designers who already have some product application ideas for a material at hand might include these ideas (as physical prototypes) in the study.

The toolkit provides facilitators with instructions to go through the four levels of materials experience one by one, as separate activities, and in the subsequent order: performative – sensorial – affective – interpretive. The ***sensorial tool*** consisted of the sensorial scale, printed on transparent paper, so it could be overlapped during the analysis of results and provide an immediate grasp of the differences between participants' answers. The sensorial level also involved asking three specific questions to users: 1) what is the most *pleasant* sensorial quality? 2) what is the most *disturbing* sensorial quality? 3) what is the most *unique* sensorial quality?

The ***affective tool*** included the affective vocabulary, printed as stickers, and the map to record participants' answers based on Russell's (2003) model of emotions. In this activity, facilitators should ask users to describe the emotional state elicited by the material and choose three representative words from the set. Then, they should place the stickers on the map rating how intense / mild, pleasant / unpleasant the selected emotions felt.

The ***interpretive tool*** consisted of the interpretive vocabulary, also on stickers, and a set of 21 pictures associated to each meaning. The pictures were not validated, yet they were included to investigate the value of visuals for detailing meanings of materials. Facilitators should ask participants to choose three meanings out of the set provided, and then associate two pictures to each chosen meaning.

For the ***performative level***, facilitators should ask participants to interact with the material for 1-2 minutes. Then, users should choose few pictures from the set provided (Figure 2), to represent the actions that the material inspired them. Facilitators and users should also name the actions and note them down on the map.

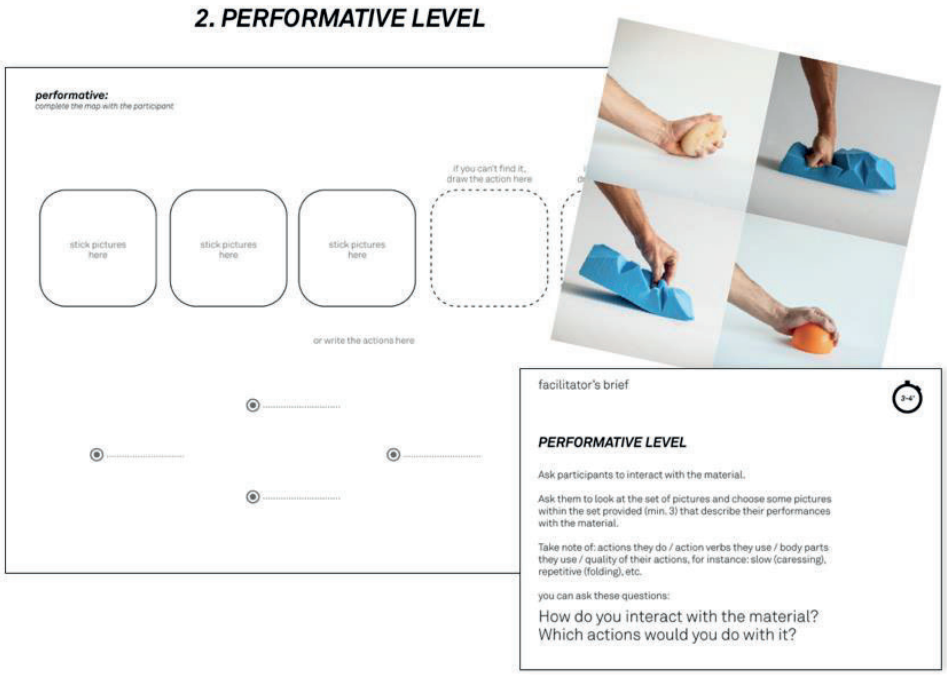

Figure 2. example maps, stickers and cards provided to support the performative level.

6.2 Workshop 1

The first workshop was conducted as part of an elective design course "Materials for design" at Delft University of Technology (Figure 3). It involved 16 design students (male: n=9; female: n=7), all attending the MSc level. Students were familiar with the notion of experience-driven design, but have limited expertise in conducting structured user studies. The workshop lasted 3 hours, including 30 minutes of introduction and 45 minutes of discussion at the end of the activity. They were asked to simulate a user study using the first version of the Ma2E4 toolkit, alternating in the role of facilitators and users. They were divided in eight couples of user-facilitator. As facilitators, they were given the draft version of the toolkit containing the instructions to lead the user study. As users, they were presented with a material sample and they were asked to describe their own experiences with it, following the instructions of the facilitator. For this workshop, we chose relatively new and unfamiliar materials: mycelium-based composites, which are materials fabricated from the growth of fungi on substrates of organic waste materials, e.g. rapeseed straws (Camere & Karana, 2017). At the end of the user test simulation, the maps through which facilitators collected the users' response

were hung on a whiteboard, grouped by experiential level (Figure 4). In the subsequent discussion, we demonstrated to the participants how results could be analyzed and what kind of interrelationships could be identified in the data.

Figure 3. pictures from the two workshops supporting the development of the Ma2E4 toolkit (left: workshop 1; right: workshop 2).

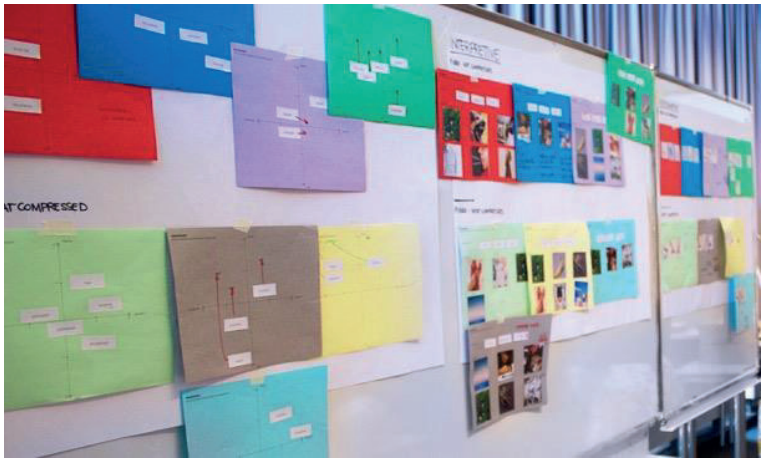

Figure 4. the maps collected and grouped by experiential level during the end discussion of workshop 1.

6.3 Workshop 2

The second workshop took place within a masterclass for design professionals on the topic of "Materials-driven design" at Delft University of Technology. A total of 8 design professionals (male: n=6; female: n=2) joined the workshop. All participants had significant expertise in materials and design research. As in the first workshop, the participants were given a brief introduction to the topic of materials experience (around 30 minutes), after which they were divided in couples to simulate a user test session. The workshop followed the same procedure of the first one.

7 Results

Both workshops provided relevant insights and demonstrated the potential of the toolkit, nurturing its development. Results from both observations and collective interviews were grouped in three categories: 1) related to the approach; 2) related to the specific components of the the toolkit; 3) related to the way the toolkit is designed (i.e. overall design). We discuss these findings in detail hereafter, supported by quotes from the participants.

7.1 The Toolkit Approach

Participants from both workshops were generally satisfied by the toolkit. The toolkit was found easy-to-use. Both workshops ran smoothly and participants had no difficulties in understanding the activities suggested. Professionals from Workshop 2 appreciated the richness of data provided by Ma2E4 toolkit, in contrast to the approaches that they were used to (*"I've done more empirical studies, structured studies (…) but I often feel that something is missing."* – professional 1). Also,

participants felt engaged in the exploration of each experiential level: "*I like how the different tools support the exploration in different moments… I like the emotional map because I had an idea of doing it* [i.e. exploring affective materials experience] *but I only had the Self-Assessment Mannequin* [i.e. the SAM, Bradley & Lang, 1994]. *But that has less to do with a material, it's more for a product. I like the interpretive also, because it's not rating…"* (professional 4). At the same time, they agreed that the tool *"is very interesting because you can really catch the influence of the different qualities of materials on the overall experience..."* – (student 3) and that it is also inspiring: "*in terms of inspiration I think it's really useful"* - (professional 2).

Furthermore, professionals from Workshop 2 have praised their significance to support the conversation with users *("I like how the vocabulary made it easier to express and talk about experiences… it really supported the conversation because normally it's so difficult to name emotions"* - professional 5). Indeed, design professionals appreciated the potential of the toolkit more than design students. This was because professionals acknowledge the investment of time and efforts that structured user studies normally require, and they valued the agile and easy-to-learn approach of the Ma2E4 toolkit.

7.2 The Toolkit components

Although the toolkit proved to be an agile and easy to use research tool, few limitations were found in the characterization of interpretive and performative qualities. Concerning the performative level, it was difficult for facilitators to simultaneously look at users' actions and choose the right pictures to represent them. Moreover, it was very challenging to identify a specific naming for the actions (i.e. fiddling instead of touching). Lastly, the pictorials provided were confusing because they showed different types of materials and shapes ("*I found it difficult because the pictures were from very different materials... if we could have pictures with the same materials, or same color... otherwise it's too different"* - student 2).

The interpretive level also entailed some confusion and difficulties. First of all, the set of interpretive pictures was found too limited by participants: "*the interpretive pictures, they were too few. They are not really meaningful to express the meanings..."* (student 7). Secondly, participants were not really sure on how to interpret the choice of the pictures, because these were not explicitly linked to each meaning (*"how can you evaluate the pictures, as data?"* – student 6). This is also related to another issue raised by participants: the difficulty in understanding how they could analyze the data collected through the Ma2E4 toolkit. "*In my experience, it's all about how you analyze. Because we had this discussion about the [interpretive] pictures, I asked the participant to specify what s/he wanted to add…and those comments are also very valuable, but how do I fit them in the data?"* (professional 3). One participant reported that showing the results of the sensorial scale as overlapped (n.d. being printed on transparent paper) was very engaging for him, because it provided a sort of immediate visualization of how participants' answers were differing (professional 2). This suggests that in order to support the analysis and interpretation of data effectively, the Ma2E4 toolkit should also tackle the representation of data so that it will help organizing findings in an informative as well as inspirational way.

Furthermore, the analysis session of the workshop made it clear that the three questions asked during the sensorial level were not necessarily related to sensorial qualities, but also to other experiential characteristics. For example, to the question *"what is the most unique sensorial quality of the material?"*, few participants answered *"its contrasting features"* (e.g. looking heavy but feeling light). The participants recommended keeping these questions rather open, in relation to all four experiential levels and their interrelationships.

7.3 The Toolkit overall design

Participants emphasized that they experienced the activities at each level as very distinct. This was mainly because the levels were presented one by one, through different envelopes. This complicated the exploration of the interrelationships between the experiential levels. As a results, the overall

design of the toolkit should be improved to facilitate a more holistic understanding of materials experience.

8 Toolkit Version 2

Based on the insights obtained from the workshops, we concluded the following points of attention which guided the further development of the Ma2E4 toolkit:

- the toolkit should provide a holistic overview to support designers in revealing the interrelationships between the experiential levels; hence, the overall design should integrate better the activities related to each experiential level;
- the toolkit should support not only data collection, but also data analysis and visualization;
- the performative level should include a vocabulary of performative qualities; the related images should be improved and possibly include similar materials in all pictures
- interpretive pictures set should be expanded and better linked to the suggested meanings.

Figure 5. the Ma2E4 toolkit, redesigned based on the insights gathered in Step 1

Accordingly, we redesigned the Ma2E4 toolkit (Figure 5) as consisting of:

1. a ***manual of instructions***, which provides a brief introduction on materials experience and tips on the toolkit usage;
2. the ***facilitator's guide***, which includes the questions and activities designers should ask and perform during the study;
3. the ***experiential characterization map***, to record participants' answers.

Next to these, the toolkit includes two sets of words (i.e. the ***affective*** and the ***interpretive vocabulary***) and a collection of images (i.e. ***the interpretive picture sets***) to be used for refining the interpretive descriptions.

The experiential characterization map is designed as a folded A3 (Figure 6), so that each experiential level can be explored separately. At the end of the test, designers/facilitators can unfold the map and have a holistic overview of participants' answers. Going through answers, they can identify interrelationships and ask more detailed questions on the motivations behind user's answers. Being formatted as ISO:A3, the map is easy to reproduce and print. The folding instructions are provided in the Ma2E4 manual of instructions and shown in Appendix I.

Few specific changes were also made at each experiential level. For the performative qualities, we developed a list of actions describing the pictorials (Figure 7). The vocabulary and the pictures were organized according to the framework presented by Angelini et al. (2015), which suggests three main categories of gestural interactions with material artefacts. The three categories are: 1) ways of ***touching*** the material (e.g. pressing it, punching it, fiddling it); 2) ways of ***moving*** the material (e.g. folding it, flexing it, weighing it); 3) ways of ***holding*** the material (e.g. pinching it, holding it gently, etc.).

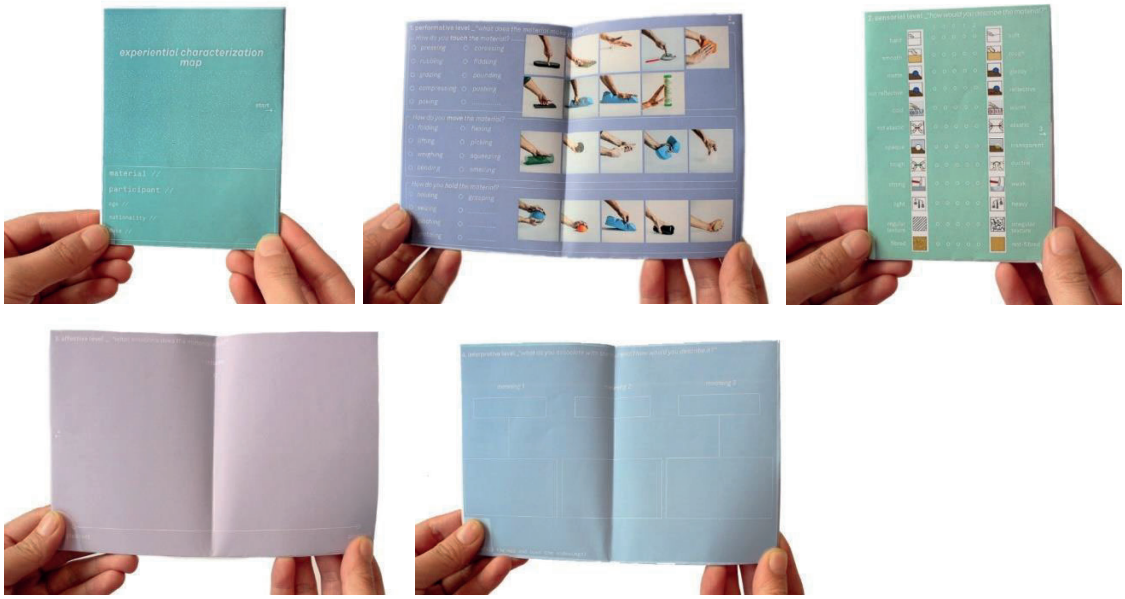

Figure 6. unfolding the experiential characterization map and revealing each experiential level separately.

The ***sensorial level*** remains unchanged, except for the exclusion of three questions concerning the pleasant, disturbing and unique qualities of materials, as these questions provided answers on a more general level and not directly related to sensorial.

Figure 7. the performative vocabulary and the pictures included in the Ma2E4 toolkit.

For the ***affective level***, the vocabulary is provided on a card instead of stickers, which would have not been practical for design professionals to reproduce (Figure 8). The graph based on Russell's (2003) model is now organized on three axes instead of four (i.e. pleasant/unpleasant and level of intensity), based on the workshop insights. Indeed, the rating of intensity was found difficult to rate as 'negative', because users were asked to select the three most important (i.e. 'intensely perceived') words to describe their emotional experience. In this version, the purpose of the third axis is to detail which of the chosen emotional descriptors is more relevant to describe the user's emotional state, assuming that all three are intensely perceived.

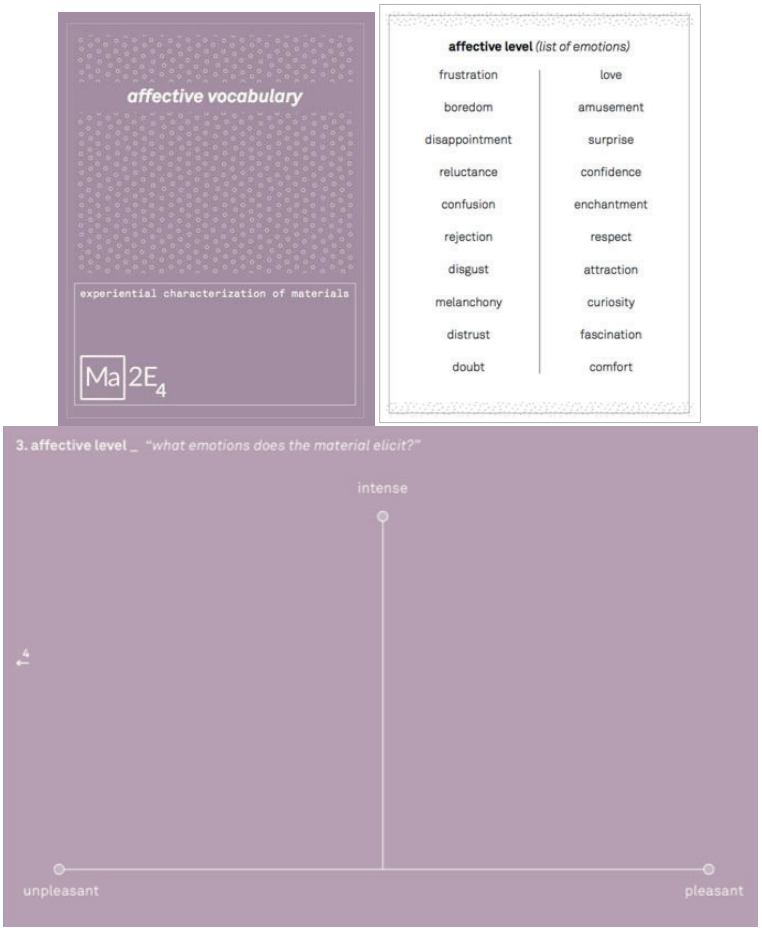

Figure 8. The affective vocabulary and the map to record participants' answers at the affective level.

Similarly, the ***interpretive*** vocabulary was also provided as a card instead of stickers (Figure 9). The set of interpretive pictures is now expanded, including 3 pictures for each meaning provided (Figure 10). As it is known that designers develop their own collections of pictures (Keller et al., 2009), which they often use as visual references, we also suggest that designers could develop their own set of visuals filling in the provided template, or expand on the provided one. To allow easy reproduction, the set of interpretive pictures is formatted as A3 sheets (Figure 10). Designers should ask users to select one picture (out of three provided for each meaning) to specify their interpretation of the selected meaning. We suggest that the pictures are cut and pasted on the map by the facilitator.
As suggested in the workshops, designers / facilitators may feel the need to deepen the conversation with users and ask the motivations behind their answers. The last step of the tool (***final reflection***) provides the opportunity to do this, unfolding the map completely and asking the three questions previously included at the sensorial level (i.e. "what is the most **pleasant** quality of the material?", "what is the most **disturbing** quality of the material?" and "what is the most **unique** quality of the material?"). Then, designer / facilitator can ask users to reflect on their previous answers, trying to catch the relations between the different experiential levels. For example, they can ask: "why do you think the material is aggressive? What are the sensorial qualities that make the material 'aggressive' according to you? And, how is this connected to the emotions you selected?", etc.

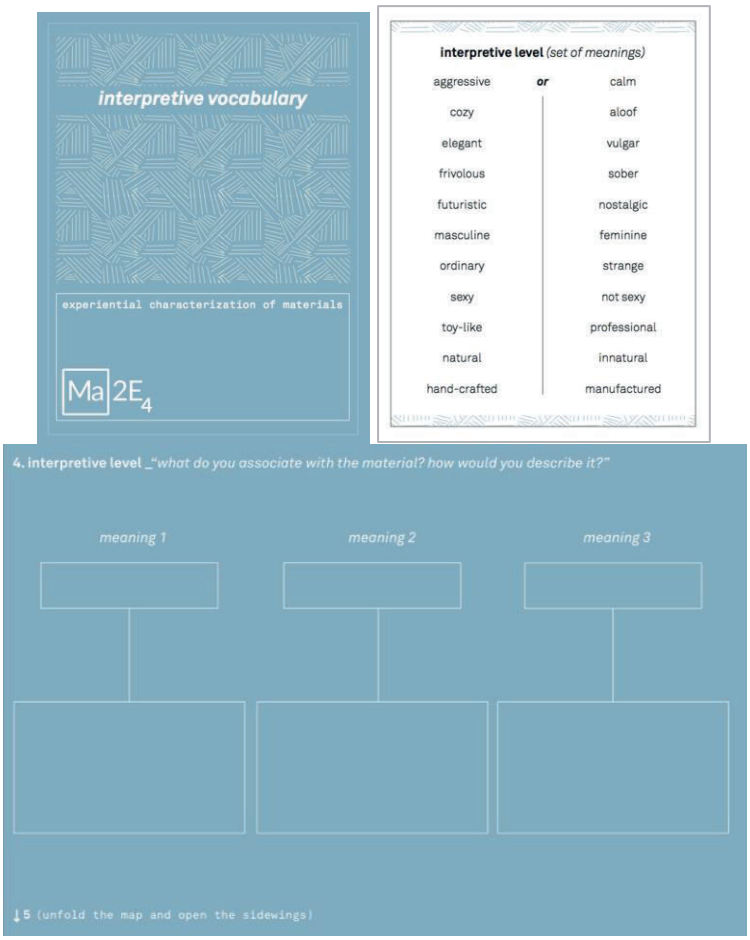

Figure 9. The interpretive vocabulary and the map to record participants' answers at the interpretive level.

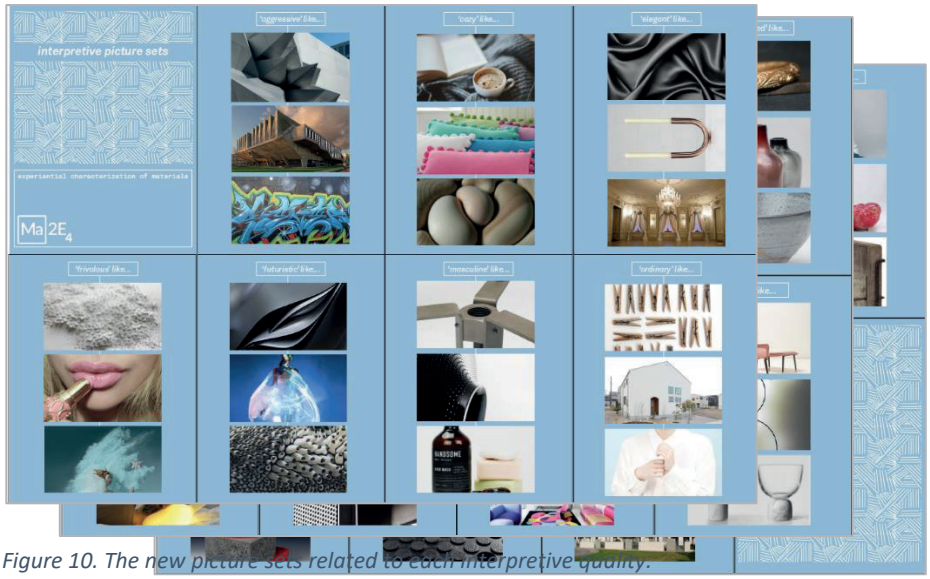

Figure 10. The new picture sets related to each interpretive quality.

9 Discussion

The new Ma2E4 toolkit was designed as flexible and agile as possible, to better support design professionals and materials developers in conducting user studies to understand how people experience a specific material. This activity, defined as the experiential characterization of materials, is particularly important in Material-driven design (Karana et al., 2015), which is increasingly chosen as an approach to envision unique product applications or to stimulate the further development of new materials. Whether it is used to characterize novel and unknown materials, or to reveal new insights about a known material, the Ma2E4 toolkit can facilitate such experiential understanding of the material at hand. The toolkit is designed to allow different uses, depending on the specific needs of the design situation. Herein, we will discuss possible situations in which the Ma2E4 toolkit could support the research activities.

The Ma2E4 toolkit allows to conduct research on one specific material or to compare the material at hand with other known ones, which is a common practice in understanding materials in design (Ashby & Johnson, 2002). Moreover, it can be used to test multiple variants of the same material. In projects where designers act as developers of new material proposals (i.e. *DIY materials*, Rognoli et al., 2015), designers can link the material variables (e.g. 'material ingredients', Rognoli et al., 2015) to the experiential qualities. Doing so, they can purposefully manipulate material properties to achieve the envisioned experiences. Moreover, while we emphasize the importance of all four experiential levels, the Ma2E4 toolkit could also be adopted to investigate one specific level in more details (e.g. affective level). As explained earlier, the tools developed for each level ground on rigorous studies conducted by scholars within the materials and design domain. They can provide reliable results for detailed understanding of a specific level. Yet, designers might also decide to adapt additional tools for a specific level, while maintaining the overarching framework. These *appropriations* are common in design methods and tools (Stolterman, 2008) and we seek to encourage professionals to approach the Ma2E4 toolkit in this way.

To analyze the data gathered in Ma2E4 studies, designers can choose between an exploratory approach or a more structured one, depending on their specific needs. Designers might use Ma2E4 toolkit to explore users' perspective and reveal new facets of a design situation (Dalsgaard, 2017). At the end of the tests, they might already identify *materials experience patterns* (Giaccardi & Karana, 2015; Karana et al., 2015) that inspire new ideas. In this case, they can decide to skip any type of structured analysis, but simply to map out the most relevant insights obtained from the study.

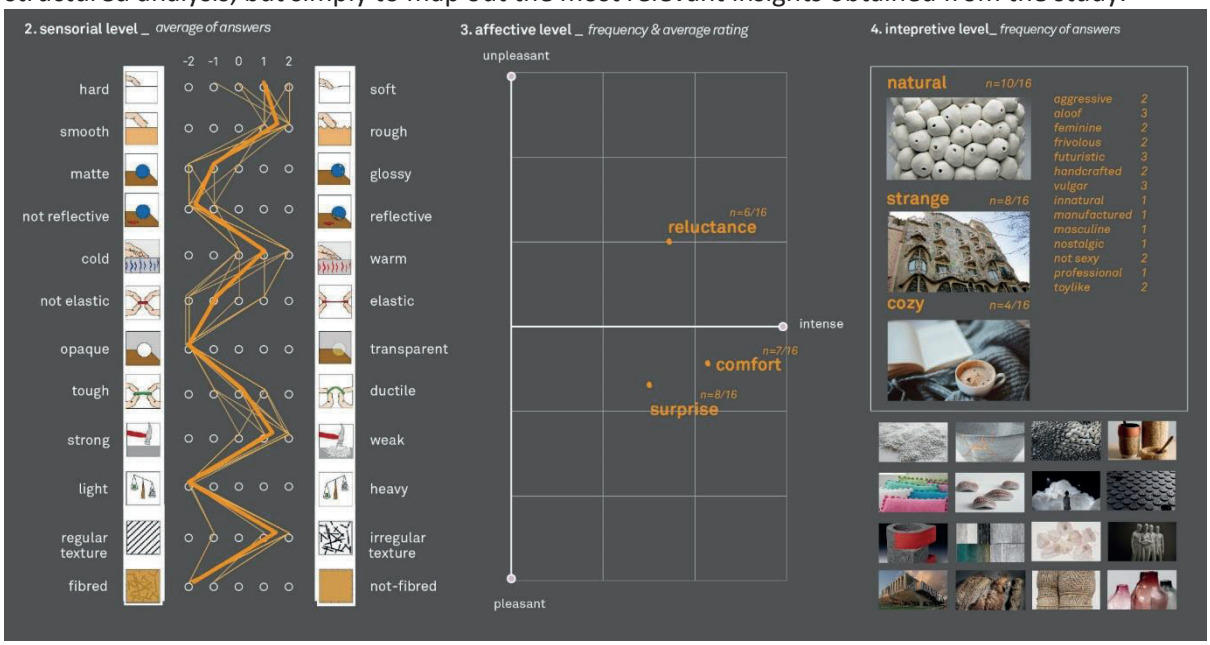

Figure 11. examples of how Ma2E4 data (for one material) can be analyzed and represented through systematic methods.

Yet, when designers or materials developers engage in larger projects, either research- or business-oriented, they might need to analyze data with a more structured approach. Despite its flexibility, the underlying structure of the toolkit allows the collection of comparable results, which can be analyzed through statistical tests, such as ANOVA (for the sensorial level, as seen in Karana, 2014; Sauerwein & Karana, 2017), frequency of choices (e.g. for the affective and interpretive qualities) and factor analysis (to identify correlations between the answers, Karana, 2009) (Figure 11).

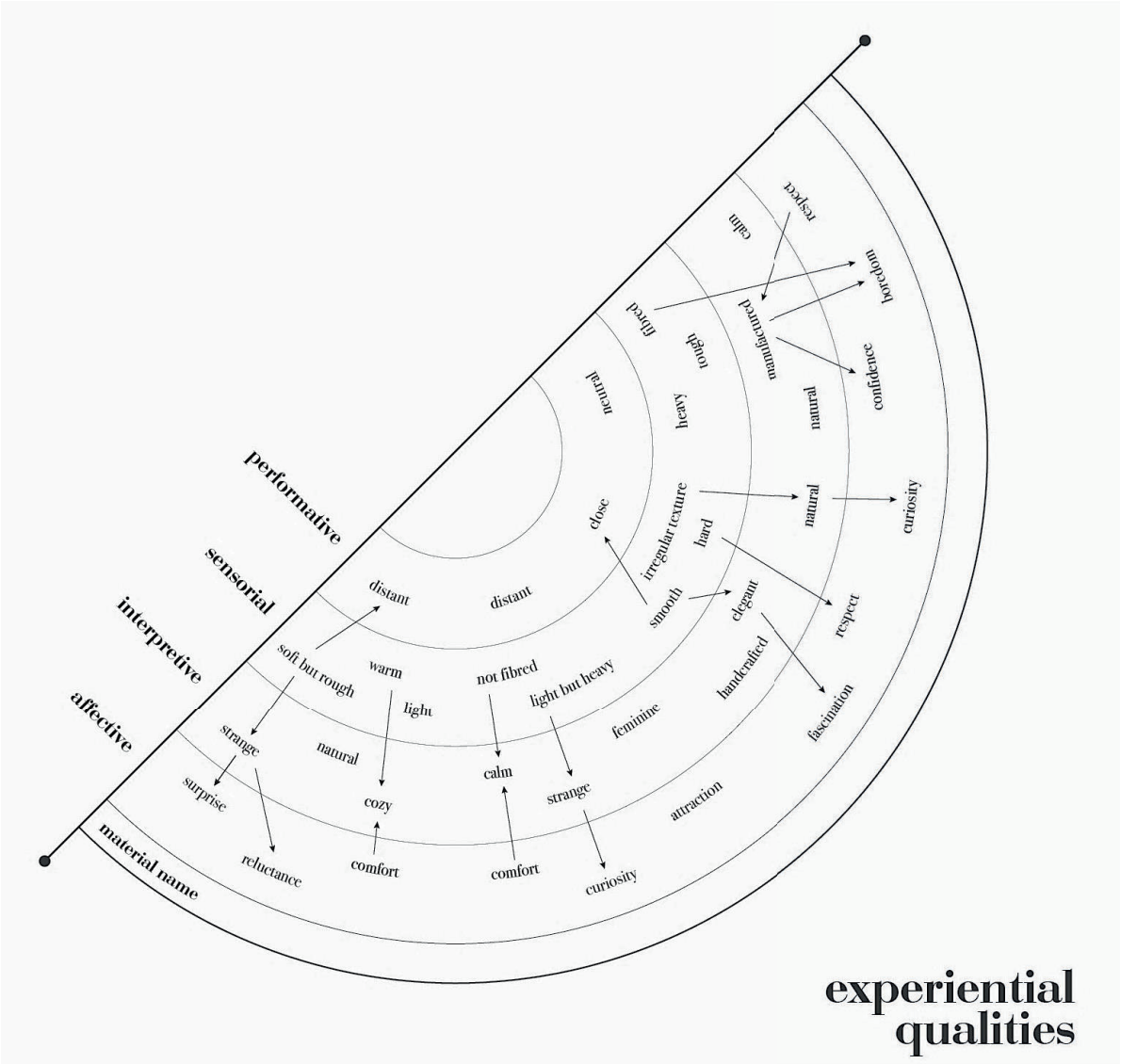

Figure 12. The canvas designed to map the materials' experiential qualities at the four levels of materials experience and their interrelationships.

The way data is visualized and communicated is also very important to stimulate reflections over users' reactions and inspire design (Sleeswijk-Visser, 2009). Keeping this in mind, we developed the experiential characterization map with a high visual component, so that once completed, opening and confronting the maps would already provide a visualization of the results. Nevertheless, it is important to further support designers in this step with a targeted tool, especially in the case of larger projects when results need to be presented in a more systematic way. We suggest as a possible solution to this the canvas illustrated in Figure 12. The canvas consists of four rings, which can help mapping the insights gathered in relation to each experiential level. It can be used to summarize the most *relevant* user insights, either based on the designers' / facilitators' own interpretation of the findings or on the structured analysis of the user responses.

We also suggest that the canvas can be used to present the interrelationships between the technical properties and the experiential qualities of materials (Figure 13), emphasizing the dualist perspective needed to understand materials. An example of how this approach can inform the further development of emerging materials is demonstrated in a nationally-funded project “Mycelium based materials for product design”. The canvas was used recently in the exhibition “Fungal curiosities”, to present the project’s preliminary results during Dutch Design Week 2017 (Montalti, 2017).

Figure 13. Exhibition ‘Fungal curiosities’ at Dutch Design Week, displaying the technical properties and experiential qualities of mycelium based composites (Montalti, 2017).

The Ma2E4 toolkit was developed based on the insights gained in two exploratory workshops. While we acknowledge that the approach and the toolkit needs further validation (e.g. on whether our design suffices to support the analysis and visualization of data), we can foresee its possible contribution to materials and product development. Further applications of the Ma2E4 toolkit, e.g. in graduation projects or in projects from design practice, will bring new insights on how the experiential characterization of materials can be conducted to inspire materials and product development. Moreover, as we speculated at the start of our journey, further work will be needed to support the performative level. This is due to the relatively recent introduction of the notion (Giaccardi & Karana, 2015) and thus to a lack of vocabulary on materials’ performative qualities. The research into the construction of a vocabulary for performative qualities of materials would inevitably support the further development of the Ma2E4 toolkit. At the present moment, the toolkit relies on existing tools and research conducted over the years in the domains of materials and product experience. Yet, its originality and relevance lies in connecting different strands of research to foster a holistic understanding of materials experience and an agile approach to this type of studies. In this way, we hope to facilitate the practice of characterizing materials experientially, to achieve a dualist understanding of materials, and further stimulating design with a specific material at hand.

10 Conclusions

The paper presents the development of the Ma2E4 toolkit, aimed at facilitating the experiential characterization of materials. Our goal is to foster the uptake of this practice by providing an agile, reliable and inspiring tool. The toolkit has been developed grounding on existing literature and

through two exploratory workshops, involving design professionals and design students. The workshops provided useful insights on the toolkit's final design, which is presented in its current version in the paper. While the toolkit needs further adjustments and validation, it has proved to support design practice in conducting user studies to understand how a material is experienced.

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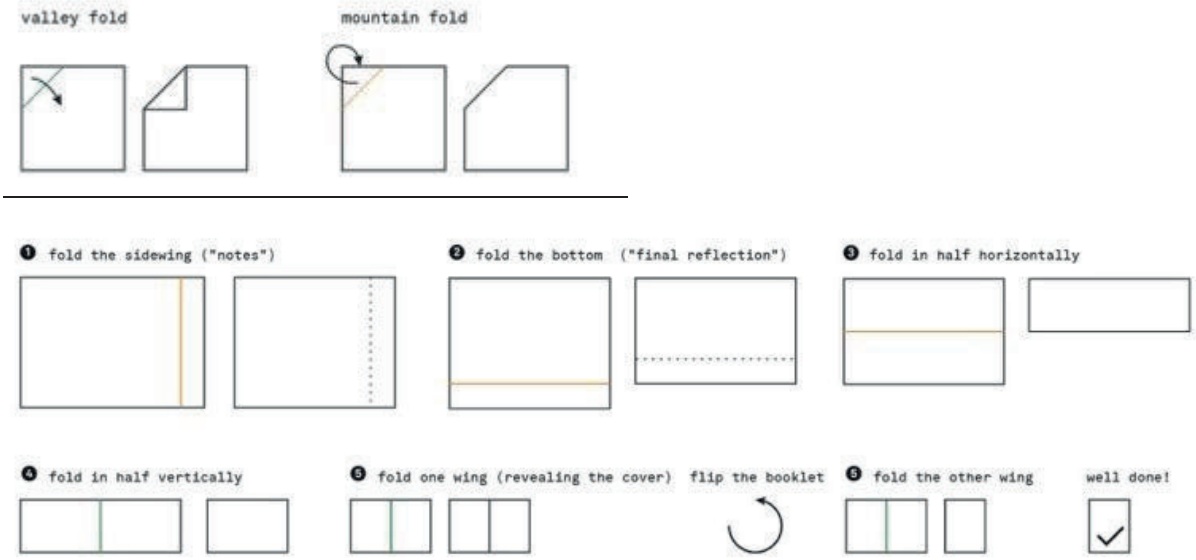
Appendix I

Folding instructions, as included in the Ma2E4 manual of instructions.



Appendix II – Ma2E4 experiential characterization map