

FORMULATING GUIDELINES FOR THE SYSTEMATIC SET-UP OF EXPERIENTIAL MATERIAL CHARACTERIZATION STUDIES: A CASE OF PLASTIC DEMONSTRATORS

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ABSTRACT

Materials can be considered from a technical and experiential perspective. However, the latter perspective is more complex to study systematically. Four intertwined experiential levels describe the overall materials experience: sensorial, interpretive, affective, and performative level. Building upon the need in experiential material characterization for comparable physical material representations to enable within-material-class comparisons and the inclusion of extensive user aspects, this paper sums up the reasoning process regarding the understanding and design of an experimental set-up and its parameters of a specific case. The case objective is to formulate guidelines for the designer/researcher to set up experiential material characterization experiments with (i) plastic demonstrator forms and (ii) by consumers. Following elements are discussed: Assessors, Stimuli, Interaction Modalities, Dependent variables, Method, and Practical considerations. Next, future experiments can be carried out in order to generate holistic plastic material data on a larger scale, that can be collected in an experiential database and used by designers throughout the design process.

Keywords: Multisensory product experience, Experiential material characterization, Materials experience, Emotional design, Human behaviour in design

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1 INTRODUCTION

In product design, materials can be considered both from a technical and an experiential perspective. This dualist understanding of materials has gained increased interest over the years (Karana, Pedgley, and Rognoli 2014; Ashby and Johnson 2010; Camere and Karana 2018) and led to a new field of materials experience both in design research and practice (Veelaert, Du Bois, Moons and Karana, 2020). Thus, a holistic approach within the design process does not only require material characterization knowledge with regard to technical properties, manufacturability and functionality that can be historically found in datasheets based on standardized tests (Ashby and Johnson, 2010; Jahan *et al.*, 2010). In addition, the experiences that materials can elicit through physical products should be considered as well to increase commercial success of both products and materials in a competitive market (Karana, Pedgley, and Rognoli 2015; Giaccardi and Karana 2015).

When aiming for a circular economy (Ellen MacArthur Foundation and McKinsey & Company, 2012) within engineering design, different focuses can be found related to materials, going from materials production, selection and the impact on future waste, to elongating the product use phase through product attachment by means of products and materials that suit the user's personality (Mugge *et al.*, 2005; Norman, 2004). This leads to an increased search for new and alternative materials that are more sustainable and suiting in a circular economy, e.g. natural material, bioplastics, recycled plastics and so on. However, these material's origin impacts both their properties and perceived aesthetics (Karana 2012; Schifferstein and Wastiels 2014; Dehn 2014). Often, such new materials struggle for adoption when introduced in the market, partly due to the lack of knowledge or data on how they are perceived and experienced by people as they are frequently implemented as surrogates or substitute materials (Salvia *et al.*, 2011; Sauerwein *et al.*, 2017; Vezzoli, 2014).

Following the Meanings of Materials Model (Karana 2010), it is the interaction between the user and a material that defines a material's meaning or meanings. However, various factors continuously influence this meaning creation, such as the product in which the material is embodied, its shape and brand, the time and context in which it is used, the background of the user (i.e. gender, age, culture, etc.), and of course the technical properties and experiential qualities of the material itself.

Considering the latter, four experiential levels are defined in literature that are intertwined and as such describe the overall materials experience (Karana, Pedgley, and Rognoli 2015; Camere and Karana 2018; Giaccardi and Karana 2015). The three first levels address the cognitive aspects of experiences, while the final level encompasses the behavioural aspects. First, the sensorial level encompasses the first encounter of our senses with a material and is as such inherently part to human experience (e.g. is the material perceived glossy or light). Within this level, the visual perception of materials and its attributes is highly important in recognizing materials, even without touching (Fleming, 2014, 2017). Second, the interpretive level follows the sensorial encounter and involves the interpretations and meanings people attribute to materials (e.g. is the material associated with masculinity or nostalgia). Third, the affective level includes the emotions that material can unconsciously elicit (e.g. does the material make me feel surprised or fascinated). Fourth, the performative level reflects our physical response or actions to the previous levels (e.g. does the material invite to caress or to fold). Camere and Karana (2018) state that:

"The experiential characterization of materials ... concerns investigating how a material is received, what it makes people think, feel and do. ... 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 'cosy'), 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')".

However, Camere and Karana (2018) acknowledge that "materials experiences can be quite challenging to study and research, and it requires a delicate balance between studies that provide both a holistic perspective ... and detailed, specific information". Indeed, a large gap is found in equivalent data support on experiential material knowledge (Piselli *et al.*, 2018; Veelaert, Du Bois, Moons and Karana, 2020; Wilkes *et al.*, 2016). Therefore, they developed the Ma2E4 toolkit for design professionals to facilitate experiential characterization of materials in an agile and inspiring matter. However, the toolkit is rather focused on specific material cases than on large scale material data that is needed for designers. Although the toolkit pays profound attention to the evaluation of various experiential material qualities, it does not involve the physical means or material samples to do so, nor a more structured analysis that can be useful for data driven design.

Conclusively, this paper aims to formulate guidelines for the systematic set-up of experiential material characterization experiments. By streamlining these studies, material characterizations on a large and standard scale can lead to an experiential database of various materials, helping designers in their design and materials selection process as they are backed by data on materials and target audience (consumers).

When looking at domains such as food science, well-founded tests and statistical procedures for sensory profiling have been embraced (Reinbach *et al.*, 2014; Sidel and Stone, 1993; Varela and Ares, 2012). These have been recently utilized for visual and tactile material characteristics as well (Faucheu *et al.*, 2015; Piselli *et al.*, 2018). Within (interior) architecture, the link between warmth/roughness perception and technical properties of building materials has also been investigated (Wastiels *et al.*, 2012a, 2012b). Conclusively, an extensive literature review (Veelaert, Du Bois, Moons and Karana, 2020) describes how various researchers respond to the methodological challenges involved in experiential material characterization studies, and articulates the need to find "abstract forms or products that do not carry too much meanings in itself so that material meaning can be projected more independently" (Veelaert, Du Bois, Moons and Karana, 2020, p. 13). To achieve a more holistic understanding of materials' experiential qualities, a transition to straightforward and streamlined set-ups of experiential material characterization studies on a larger scale - facilitating data driven design - is still a stumbling block for many material/design researchers.

2 CASE

Multiple studies emphasize the specific context or objectives within materials experience studies that require different approaches for this experimental set-up of experiential material characterization (Camere and Karana 2018; Karana and Hekkert 2010). Next to context-specific material data, generic data of experiential material qualities can also offer insights for designers in the beginning of their design process (Veelaert, Du Bois, Moons and Karana, 2020). Hence, experiential studies can start from contextualized materials in a specific product (e.g. (Karana, Hekkert, and Kandachar 2009; Crippa, Rognoli, and Levi 2012)), or can employ abstract, decontextualized samples (e.g. (D'Olivo *et al.*, 2013; Wastiels *et al.*, 2012a)). This way, experimental conditions are easier to control as the material is assessed independent of context. Therefore, this paper builds upon a specific case that arises from previous experiences and needs defined in (Veelaert, Du Bois, Moons and Karana, 2020): (i) need for within-material-class comparisons, (ii) need for physical material representations, and (iii) need for integration of extensive user aspects. First, as little comparisons within material classes can be found - and especially within plastic materials - this case will focus on the facilitation of comparing plastic materials (i.e. virgins, recycled plastics, bioplastics, etc.) that face issues within a circular economy such as sustainable perception or being identity-less imitation materials (Karana and Nijkamp, 2014; Rognoli *et al.*, 2011; Veelaert, Du Bois, Moons, De Pelsmacker, *et al.*, 2020). Furthermore, Fisher (2004) addresses the specific significance of plastic materials for consumers' perception of objects, and its affective consequences. Second, this case employs a standard demonstrator form that is developed in previous research (Veelaert *et al.*, n.d.), see Figure 1, as an answer to the proposed "abstract in-between form that allows an equal and thus constant presentation of various materials, but is varied in itself" (Veelaert, Du Bois, Moons and Karana, 2020). Such a complex demonstrator form allows for more controlled experimental conditions while still facilitation multimodal free exploration of its material.

Third, as a large number of studies involve designers in characterization experiments or limited user aspects beyond age and gender, this case will take on the challenge to specifically address and trigger consumers in a dynamic experiential material characterization as end-users of products/materials. This way, future large-scaled studies can be combined with consumer segmentation for marketing purposes.



Figure 1. Demonstrator forms shown from two perspectives, based on (Veelaert *et al.*, n.d.).

3 RESEARCH AIM

This paper summarizes the reasoning process and argumentation regarding the experimental set-up and its parameters of a concrete case within materials experience studies. The objective is to formulate guidelines for the designer to systematically set up experiential material characterization experiments with (i) plastic demonstrator forms and (ii) by consumers. Therefore, this research aims to identify a set of appropriate methodological choices as a first step towards streamlined future material characterizations to build up an experiential 'database' of various plastic materials such as virgins, recycled plastics, bioplastics, etc. To structure the work, the next Section is based on the encryption categories of a previous literature review on this matter (Veelaert, Du Bois, Moons and Karana, 2020) and a practical handbook on sensory evaluation (Kemp *et al.*, 2018): (i) stimuli, (ii) interaction modalities, and (iii) dependent variables, (iv) assessors, and (v) method.

4 GUIDELINES FOR EXPERIMENTAL SET-UP: EXPERIENTIAL MATERIAL CHARACTERIZATION OF PLASTIC DEMONSTRATORS BY CONSUMERS

4.1 Assessors

As previously stated, this case focuses on **consumers** as participants, as compared to designers or expert sensory panels. Since consumers can be considered as naïve and untrained assessors, and can also be involved in affective judgements. In addition, **large-scaled** experiential studies with consumers can also offer segmentation opportunities when including extensive user aspects beyond merely age and gender, such as culture, personality traits and values. In the case of continuous experiments over time, a large panel size of consumers can be achieved to generalize findings. The higher the number of assessors, the higher the power of the statistical test that can be performed to analyse the data and improve discrimination between the material stimuli (Kemp *et al.*, 2018). Even for preliminary results, at least thirty assessors per cell are recommended (e.g. at least thirty men and thirty women when comparing material perception based on gender), or preferably even hundred participants (Brybaert, 2019; Sitanshu Sekhar Kar and A. Ramalingam, 2013; Wilson Vanvoorhis and Morgan, 2007).

4.2 Stimuli

Within experiential characterization, the greater part of studies involve **physical samples** (Veelaert, Du Bois, Moons and Karana, 2020) that are stated by Martín *et al.* (2015) to be still the standard. However, physical stimuli can reveal themselves in both contextualized product samples and decontextualized abstract samples. For greater experimental control, abstract shaped specimens are often recommended (Piselli *et al.*, 2018; Veelaert *et al.*, 2019, n.d.). As clarified in the previous sections, the physical stimuli in this case involve a set of standard demonstrator forms that are developed specifically for **one material class: plastics**. However, within-material-class comparisons in this case can still be going from well-known virgin plastics (e.g. PP, PE, ABS), to recycled plastics (both pure and mixed virgins) and bioplastics (e.g. PLA). This material class is chosen as it is not yet studied on its own within experiential characterization although it represents a material class that is familiar and widely used in everyday products. The demonstrator forms shown in Figure 1 is designed to be injection moulded so that high-end quality can be achieved (Veelaert *et al.*, n.d.).

4.3 Interaction modalities

As this case is characterized by physical material samples for within-class comparisons (see Section 4.1), the experiment's interaction context is of great importance. Although various interaction modalities and senses can be employed or combined, touch and vision are found to be most dominant within the appraisal of materials (Karana 2009; Sauerwein, Karana, and Rognoli 2017; Schifferstein and Wastiels 2014). This is in contrast to the fact that it is hard to isolate the senses as human behaviour and perception are intrinsically multisensory (Schifferstein 2010; Dacleu Ndengue, Juganaru-Mathieu, and Faucheu 2017). Based on literature (Chen and Chuang, 2014; Veelaert, Du Bois, Moons and Karana, 2020) and the developed demonstrator form (Veelaert *et al.*, n.d.), this case focuses on **multimodality** through dynamic touch (Hope *et al.*, 2012) and free exploration, and thus approaches the actual phase of use of a product and its material (Crilly *et al.*, 2009; D'Olivo *et al.*, 2013). Conclusively, the complex demonstrator form is aimed at evoking a holistic, multisensory

interaction, triggering participants into extensive exploration and manipulation of its materials using all senses (Veelaert *et al.*, n.d.). This way, it is possible to facilitate the understanding of all experiential levels, including performative actions such as rubbing, playing, picking up or grabbing a sample (Camere and Karana, 2018; Chen and Chuang, 2014).

4.4 Dependent variables

Following the Materials Experience Framework (Karana, Pedgley, and Rognoli 2014) and its practical translation into the Ma2E4 toolkit (Camere and Karana, 2018), four experiential levels can be incorporated as dependent variables within experiential characterization of materials: sensorial, interpretive, affective, and performative. However, the two first levels are most commonly involved in past experiments (Veelaert, Du Bois, Moons and Karana, 2020) and in the development of the demonstrator form (Veelaert *et al.*, n.d.), as they are usually more approached from a semi-quantitative perspective in contrast to a more qualitative evaluation of emotions or the observation of performative actions.

The vocabulary of the Ma2E4 toolkit mentions twelve **sensorial** attributes (hard/soft, smooth/rough, matte/glossy, not reflective/reflective, cold/warm, not elastic/elastic, opaque/transparent, tough/ductile, strong/weak, light/heavy, regular texture/irregular texture, fibred/not-fibred), eleven **meaning** sets (aggressive/calm, cosy/alooof, elegant/vulgar, frivolous/sober, futuristic/nostalgic, masculine/feminine, ordinary/strange, sexy/not sexy, toy-like/professional, natural/unnatural, hand-crafted/manufactured), twenty **emotions** (frustration, boredom, disappointment, reluctance, confusion, rejection, disgust, melancholy, distrust, doubt, love, amusement, surprise, confidence, enchantment, respect, attraction, curiosity, fascination, comfort), and proposes twenty-two **actions** (pressing, rubbing, grazing, compressing, poking, caressing, fiddling, pounding, pushing, folding, lifting, weighting, bending, flexing, picking, squeezing, smelling, holding, seizing, pinching, grabbing, grasping...), see also (Angelini *et al.*, 2015; Cutkosky, 1989; Lederman and Klatzky, 2009). However, additional experiential qualities can be interesting for characterization experiments too, as used in previous work focussing on (recycled) plastics (Veelaert *et al.*, n.d.; Veelaert, Du Bois, Moons, De Pelsmacker, *et al.*, 2020).

A final consideration relates to assessing the experiential levels one by one or randomly mixing them together. For the ease of understanding for consumers, and following the structure of the Ma2E4 toolkit, we propose to sequentially assess attributes per experiential level in the context of this specific case.

4.5 Method

4.5.1 Measurement of constructs

Although some experiential qualities might be less relevant in the context of plastics, a more important consideration comes into play, next to the extensive list of attributes available. The measurement of these experiential constructs can be done in different ways, but should ideally be streamlined for future database building. Largely derived from marketing research and sensory evaluation within food science, four main categories of sensory tests can be distinguished: descriptive testing, discrimination testing, hedonic test, and free impressions. However, within experiential material characterization, descriptive scaling method by means of the **semantic differential scaling method** (SDM) (Osgood *et al.*, 1957) is most frequently used (Hsu *et al.*, 2000; Petiot and Yannou, 2004; Veelaert, Du Bois, Moons and Karana, 2020). It has also been applied in the sensorial scales of Karana *et al.* (Karana, Hekkert, and Kandachar 2010; Karana, Hekkert, and Kandachar 2009) and within the Ma2E4 toolkit for the characterization of sensorial attributes (using clarifying pictograms for untrained respondents) and interpretive characteristics (Camere and Karana, 2018). To provide a midpoint for neutrality, an odd number of scale points is preferred (Lilley *et al.*, 2016) and approaches a more interval-based scale. Moreover, odd scales are used in 85% of past experiential scaling experiments (Veelaert, Du Bois, Moons and Karana, 2020) that employ usually five (preferred for translation into experiential characterization map; (Camere and Karana, 2018)) or seven points (for more detail).

With regard to this paper's case, we propose to stay consistent and adopt these unstructured scales with pairs of bipolar adjectives at the beginning and end of the scales (Ledahudec *et al.*, 1992). However, in order to converge interval-based statistical potential, equal distances should be emphasized by using signed numbers between the opposite pairs, preferably with a continuous slider as well so that participants can select any point between 1 and 5 or between -2 and +2. For example, the scale of the sensorial attribute Glossiness looks like "Very glossy -2, -1, 0, 1, 2 Very matte".

4.5.2 Experimental design structure

Randomisation is an important factor to consider in the experimental design of material characterization studies, especially in large-scaled experiments. In order to minimize fatigue and order effects it is recommended to randomize (i) the selection, (ii) the order, and (iii) the position (left versus right) of the experiential qualities/pairs. Of course, this implies that it is more easily done through a digital survey as compared to characterization exercises on paper. Section 4.3 already summed up the extensive list of experiential qualities over four levels, but only a selection can be questioned at once per participant, leading to a between-subjects design that is easier to set up, shorter and slightly minimizes learning and transfer across conditions (Charness *et al.*, 2012). Moreover, when the aim is to experientially characterize 'all plastics', i.e. a great variety of plastic variations over time, a random selection of available material stimuli must be made as well, leading to another between-subjects factor. This combination is defined as a balanced incomplete block (BIB) design and requires specific data analysis such as analysis of variance or ANOVA (Kemp *et al.*, 2018).

With regard to sample presentation techniques, a serial or sequential monadic design is most common, in which material samples are presented independently, one after another (Kemp *et al.*, 2018). However, for within-material-class comparisons of plastic demonstrators in this case, a reference framework by means of a simultaneous **comparative design** could be more beneficial for untrained consumers that might find it easier to assess stimuli in relation to each other instead of absolute (Cleaver, 2018), since human perception is inherently holistic and comparative (Pagès *et al.*, 2010). Thus, this way participants are given a random set of material demonstrators that each need to be assessed are allowed to reassess and compare multiple materials with each other.

4.5.3 Factors affecting measurements

Consumer judgements can be easily influenced by bias due to psychological factors, as summed up by (Kemp *et al.*, 2018). In the context of experiential material characterization, several errors can be expected of which one should be aware in setting up experiments. First, **stimulus errors** occur when assessors focus on prior knowledge when rating a sample (clues such as packaging or style), instead of their perception of the material itself. We aim to diminish this effect by providing standard demonstrator forms so that irrelevant influence of contextual factors is downsized or at least kept constant over multiple materials. Second, **halo effects or proximity errors** occur when (untrained) assessors score consecutive attributes in a similar way as compared to when these attributes would be questioned separately. This effect can be expected with untrained assessors, but can be countered by involving a limited number of attributes, separating sensorial attributes versus interpretive characteristics, and randomising their order. Third and similarly, **order effects** occur when an assessor is influenced by the order of questions, samples or attributes. This can be decreased by randomizing the order of material sample presentation. Fourth, **central tendency errors** occur when participants avoid extremes and prefer scale middle points, but can be reduced by exposing them to a wide range of samples and a large enough scale. Overall, the combination of using the proposed standard demonstrator forms as material stimuli (Section 4.2), as well as a randomisation of both stimuli and attributes (Section 4.5.2), is expected to reduce these errors in experiments of experiential material characterization.

4.5.4 Practical

Finally, practical considerations also count in setting up experiential material characterization experiments. Both budget and feasibility depend on the timing or test **duration** that is possible and desirable. Previous literature review (Veelaert, Du Bois, Moons and Karana, 2020) reveals that the number of stimuli in experiential material characterization experiments varies between 3-96 material samples with a median of 10 samples. The number of scale items differs between 1-34 items with a median of 10 items. When taking into account both the number of stimuli and the number of semantic scales that need to be assessed for each material sample, a delicate balance must be intended. Therefore, we propose to aim for 3-5 material samples that are assessed on 5-10 experiential attribute pairs, balancing a total of 25-30 assessments to be made by each participant. Overall, a maximum total time of twenty minutes per experiment seems achievable, including segmentation questions. When the motivation of the consumer can be increased by appropriate feedback or fun elements, different scenarios could be proposed, i.e. a short, medium and long version of the test, so that one can choose to repeat the experiment with additional materials and/or attributes.

5 DISCUSSION

Although this paper presents guidelines for an experimental design that is limited to our own case of experiential material characterization, several aspects can be generalized within this scenario. First of all, it is important to define the aim of the experiential study: is the objective to generate qualitative experiential information about one new material that can be applied in a specific project (e.g. Material Driven Design), or is it to compare a broad set of different materials with one another? The former option is more case-specific and allows to go more in detail and collect more qualitative material information, while the later sprouts from a more holistic perspective to collect data on a large scale which offers opportunities to link this data to consumer segmentation information. Overall, we see opportunities in always comparing materials in the beginning of setting up an experiential database, while in the end when a basic amount of data has been generated, new data can be added by means of specific material studies.

In addition, when focussing on a holistic or generic perspective when collecting experiential material data, it is important to consider the importance of context within materials experience. Indeed, meanings of materials are influenced by contextual factors such as the products they are embodied in, where these products are used. To overcome this context issue, the proposed guidelines build upon the use of an abstract demonstrator form that is aimed to be independent of context, to allow controlled experimental conditions. However, when conducting characterization experiments with these demonstrator forms, it is possible to include "envisioning factors" by asking participants to envision the demonstrator's material in a particular product or situation. Thus, the abstract form can offer flexibility despite standardization of the form, and as such increase time efficiency and practical difficulties.

Conclusively, the next step in future research should be to start carrying out experiential characterization studies following the proposed guidelines and thus, gather experiential data on a large set of plastic materials such as virgins, bioplastics and recycled plastics (data-driven design). Together with large-scale information on user aspects (of consumers), relationships can be sought between different types of plastics and their (sustainable) perception in order to facilitate their commercial success in a circular economy.

6 CONCLUSION

In this paper, we presented a selection of experimental guidelines that can be further used by designers to set up experiential material characterization studies within a specific case in which we focus on plastic materials (virgins, recycled, bioplastics, etc.), made physical by means of standard demonstrator forms, and assessed by consumers. A schematic overview of these guidelines is presented in Figure 2.

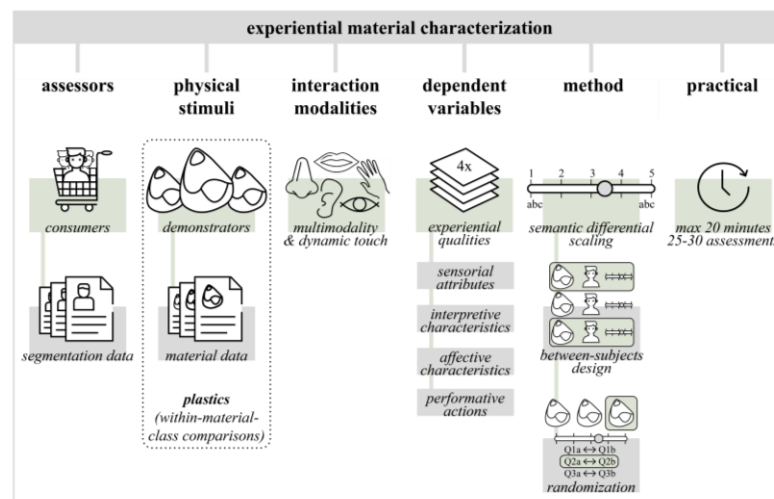


Figure 2. Schematic overview of guidelines for experiential characterization studies.

To sum up, an experimental design involving the following elements was proposed: (i) experiential characterization by consumers in large-scales studies for segmentation opportunities based on more extensive user aspects, (ii) standard physical demonstrator form in various plastics for greater experimental control and within-material-class comparisons, (iii) approaching use phase through

multimodality and dynamic touch to offer an holistic, multisensory interaction with extensive material exploration to facilitate the characterization of all experiential levels, (iv) assessing qualities within these experiential levels separately instead of mixed together to ease understanding, (v) and by using the semantic differential scaling method with five-point scales, a continuous slider and signed numbers between opposite pairs, (vi) a between-subjects design with randomization of the selection, order and position of experiential qualities on scales, as well as a random selection of a set of plastic demonstrators in a comparative design set-up, (vii) and finally aiming for a balance of 25 to 30 assessments (material x quality) per participant within a total duration of twenty minutes.

To conclude, we hope these guidelines offer a common starting point for design researchers to set up experiential characterization studies with consumers and plastic materials so that experiential data can be gathered and shared on a large scale, and relationships with extensive user aspects can be investigated.

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