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The Identity of Recycled Plastics: A Vocabulary of Perception

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Abstract: As designing with recycled materials is becoming indispensable in the context of a circular economy, we argue that understanding how recycled plastics are perceived by stakeholders involved in the front end of the design process, is essential to achieve successful application in practice, beyond the current concept of surrogates according to industry. Based on existing frameworks, 34 experiential scales with semantic opposites were used to evaluate samples of three exemplary recycled plastics by two main industrial stakeholders: 30 material engineers and 30 designers. We describe four analyses: (i) defining experiential material characteristics, (ii) significant differences between the materials, (iii) level of agreement of respondents, and (iv) similarities and differences between designers and engineers. We conclude that the three materials have different perceptual profiles or identities that can initiate future idea generation for high-quality applications. The study illustrates the potential of this evaluation method. We propose that designers can facilitate the valorization and adoption of these undervalued recycled materials, first by industry and ultimately by consumers as well.

Keywords: design from recycling; plastic waste; materials experience; aesthetic perception; circular economy

1. Introduction

The growing number of (new) materials [1] leads to a complex and time-consuming materials selection process in industrial design engineering [2]. Additionally, in the context of our expanding consumer society, the role of plastics within product design has been essential [3] since they offer designers great freedom in shaping and manufacturing their products. Consequently, plastics are widely used for consumer goods such as toys, housings, packaging, etc. Inevitably, an increasing amount of products leads to an increasing amount of (plastic) waste as well [4]. Considering the future scarcity of raw materials, there is a clear need for sustainable product development in a circular economy [5,6]. Hence, engineers and product designers are addressed to rethink the products' life cycle and to retain its plastic materials in closed loops [7]. The increasing attention to sustainable and circular product design requires industry to substitute traditional materials with alternatives such as bio-plastics or materials derived from waste (e.g., recycled plastics) [8–10]. Consequently, within Europe, the industrial interest in the field of polymer recycling is ever-growing [11].

The research presented in this study is part of the project 'Design from Recycling', supported by industry in Flanders, one of the Belgian regions, that examines how to design with recycled plastics'.

More particularly, it focusses on the challenge of using these recyclates in high-quality products for industrial mass production, instead of low-grade applications and downcycling practices [12]. While Design 'for' Recycling emphasizes the recyclability at the end of a product's life, Design 'from' Recycling actually closes the intended loop through the design and manufacture of products made from existing recycled (plastic) flows. Put differently, it initiates a new product life cycle for the plastic waste that would otherwise be landfilled or incinerated, without extracting new resources [5,13,14].

Generally, two types of incoming plastic waste material can be distinguished: post-industrial waste and post-consumer waste. Post-industrial waste consists of plastic scrap that arises in the production plant itself and that can rather easily be collected and reused as long as it is not contaminated, leading to minimal quality loss or change in appearance. In contrast, our focus lies on post-consumer waste that consists of multiple and/or contaminated polymers (e.g., polypropylene, acrylonitrile-butadiene-styrene) that have already endured a full life cycle [15], making it more difficult to control quality and appearance. As chemical recycling is not yet fully developed on an industrial scale, nowadays, mixed plastic waste is mechanically recycled through a process of sorting, washing, shredding and reprocessing as flakes, allowing industrial processing such as extrusion and injection molding as a final step to new product applications [16], even high-quality products. The result of this recycling process allows to technically characterize recycled material samples through standardized lab tests, leading to material properties that can be easily integrated into material databases (e.g., CES Material Selector). From an engineering perspective, such databases are the start for materials selection and currently, mainly technical and objectively measurable data is taken into consideration.

However, in terms of material knowledge considerations in product design, literature indicates that a balance is required between technical properties on the one hand, and experiential characteristics on the other [17–19]. Van Kesteren [20] states that "for high-quality products, product designers should select materials that comprise in both aspects". To accomplish this, collaboration is needed between engineering and user-centered design [21]. Although post-consumer plastic waste offers a twofold environmental benefit as no new resources are required and less material is discarded [14,22], the origin of these materials does have an impact on the perceived aesthetics and material experience, compared to their virgin (or even post-industrial) counterparts [10,23]. The usual strategy to simply substitute and mimic traditional materials in existing products and molds, without considering the design consequences, has become insufficient for implementing post-consumer recycled plastics [12,24–27]. Due to the lack of technical excellence, from the industry's point of view, the current perception of recyclates is limited to the concept of surrogates [12], which deters the industry from implementing recycled plastics in high-quality products in the broad market. Instead, post-consumer recyclates are applied in low grade, bulky outdoor products, such as flowerpots.

"Surrogate" [28] products made of recycled plastics often fail on both the functional and the symbolic level when introduced to the market [29–31]. Despite life cycle advantages, recycled materials are not necessarily received in a positive way by either its industrial users (e.g., material engineers and designers) or by consumers when embodied in daily products [10,32]. Rognoli et al. [28] state that: "The term 'surrogate' not only evokes the idea of substitute, but it also usually adds a negative value: the surrogate is a product of lower value, used in place of a genuine one. Be a 'surrogate' means not having its own identity". Consequently, such new materials often experience a struggle for adoption in high-quality applications due to their lack of identity [10,14,28], similar to other emerging materials [33] such as bioplastics.

A material's identity is partly created by the experience(s) the material evokes with people. Therefore, to approach recycled plastics from a user-centered perspective, we build upon the Materials Experience Framework [34]. A material is experienced on four levels that interact with each other and with external aspects such as context, product, and user [35]. A material can be glossy and smooth (sensorial level), expressing an elegant or professional character (interpretive level; meanings or associations), eliciting confidence and respect (emotional level), and can trigger users to enfold the material or product (performative level) [29]. Karana et al. ([29], p. 37) state that "this requires qualifying the material not only for what it is, but also for what it does [30], what it expresses to us, what it elicits from us [34], and what it makes us do [36]". The literature indicates that 'meaning-evoking patterns' or relationships can be identified between the different experiential levels of materials [37]. In this research, we focus on the two main levels, i.e., sensorial and interpretive level, as these are most elaborated in practice [38]. Thus, when considering these expressive patterns in the design of new products, one can respond to and influence how people experience and appreciate the sensorial and interpretive characteristics recycled plastics, and ultimately improve the introduction and commercial success of recycled plastics [13,34].

While the environmental performance [27] and technical functionalities [16,25,26] have been examined to great extent by industry and academia. In contrast, additional research is needed on the user-centered or experiential perspective of plastic recyclates. As designing with recycled materials is becoming indispensable in the context of a circular economy, we argue that understanding how post-consumer recycled plastics are perceived is essential to achieve successful application in practice. Thus, a gap remains concerning experiential insights and descriptive data on materials, that would help designers to develop effective strategies to manipulate meaning-creation and to formulate meaningful material identities. This way, and in collaboration with material engineers, such new and undervalued materials can be successfully positioned on the market, which is needed to increase the valorization of recycled plastics in the design of new and high-quality products [13]. With respect to experiential material characterization, previous work [39] showed that most studies are conducted on small sample sizes (e.g., 10 to 15 participants in [40,41]), with craft or do-it-yourself (DIY) materials instead of mass recycled plastics (e.g., [13,42]), and/or without standardized stimuli produced with high-quality on an industrial scale (e.g., [43,44]). Therefore, the first aim and contribution of this research is to study the experiential qualities of three types of exemplary recycled plastics, on a relatively larger scale than previous studies, with representative materials, and with standardized stimuli and measure scales, which contributes to material knowledge from a user-centered perspective.

Perception is a subjective matter and depends on context and users. As we aim to measure users' perceptions of recycled materials, we focus on two main dimensions of experiential material qualities: the perception of sensorial attributes (which includes aesthetic appearance, touch, etc.) and the interpretive characteristics (that include meanings and associations regarding quality, sustainability, etc.). The (potential) perceptions of these experiential material qualities by multiple users are summarized and contained in the 'material identity' which can be the starting point to market a recycled material. In this study, we focus on two important stakeholder groups that encounter new recycled materials early in the life cycle, i.e., material engineers and designers who will embody recycled materials in new consumer products. Furthermore, at this stage, designers still have the ability to enhance and/or adapt the inherent sensorial and experiential material qualities, in collaboration with material engineers, i.e., through computation of the material by processing techniques, color additives, more/extra sorting steps, etc. This is essential as designers have to optimize the whole product perception and interaction with its user, and must therefore communicate with material engineers. Consequently, the second aim and contribution of this study is to understand how high-quality post-consumer recycled plastics are perceived by these two industrial stakeholders, with a focus on sensorial attributes and interpretive characteristics, and to detect the potential difficulties in their communication (e.g., one stakeholder group might perceive more and/or other characteristics). The following sub research questions can be formulated:

- (RQ1) Which experiential qualities best describe three types of recycled materials (i.e., what are the prominent sensorial and interpretive characteristics)?
- (RQ2) What are the significant differences in material perception between recycled materials?
- (RQ3) What are the similarities (RQ3.1) and differences (RQ3.2) between the material perception of designers and engineers (i.e., level of agreement on experiential qualities versus significant differences)?

2. Conceptual Framework for Experiential Characterization of Materials

In order to study material perception, we build upon the frameworks of sensorial scales [45] that are commonly used for attributing meanings to materials. Previous research [12] shows that these scales are a valuable tool to facilitate the sensorial evaluation of materials—also for non-designers—and to initiate a more in-depth exploration of a material's perceptions. This approach represents various sensorial attributes by means of both verbal and visual opposites on a five-point semantic differential scale. Three existing frameworks or methods are explored and compared to measure sensorial attributes as proposed by Karana and Van Kesteren [37,45,46]. They are shown in Appendix A. The sensorial attributes (semantic opposites) that are mentioned in at least two lists are selected: Glossiness, Transparency, Colorfulness, Color intensity, Softness, Ductility, Weight, Strength, Elasticity, Texture, Odor and Temperature. However, reflectiveness is excluded as it is considered irrelevant in the specific context of recycled plastics. The same goes for the attribute of 'transparency' (since all mixed recyclates are opaque). However, this item is retained as a control item to evaluate whether participants were attentive. In addition, in line with previous research [45], the list is extended with more attributes related to strength as this property can be interpreted in different ways from a technical material perspective, depending on the applied force (compressive, tensile, impact, shear, etc.): Stiffness, Brittleness, Scratchability, Greasiness, and Acoustics.

Similar to the procedure for sensorial attributes, an experiential scale with semantic opposites is also compiled to evaluate the interpretive characteristics of recycled materials, and thus the associations (meanings) they evoke. First of all, Karana's nine meaning sets are selected [37], which are proven to be clear, understandable, and relevant for material appraisals: Aggressive-Calm, Cozy-Aloof, Elegant-Vulgar, Frivolous-Sober, Futuristic-Nostalgic, Masculine-Feminine, Ordinary-Strange, Sexy-Not sexy, Toy-like-Professional. Furthermore, this list is extended with eight adjective pairs based on Ashby and Johnson's [3] list of 'perceived attributes' and used meanings by Van Kesteren et al. [46]: Delicate-Rugged, Disposable-Lasting, Formal-Informal, Cheap-Expensive, Classic-Trendy, Honest-Deceptive, Mature-Youthful, Traditional-Modern.

Conclusively, seventeen sensorial attributes and seventeen interpretive characteristics are used for the experiential characterization of recycled plastics by designers and engineers.

3. Materials and Methods

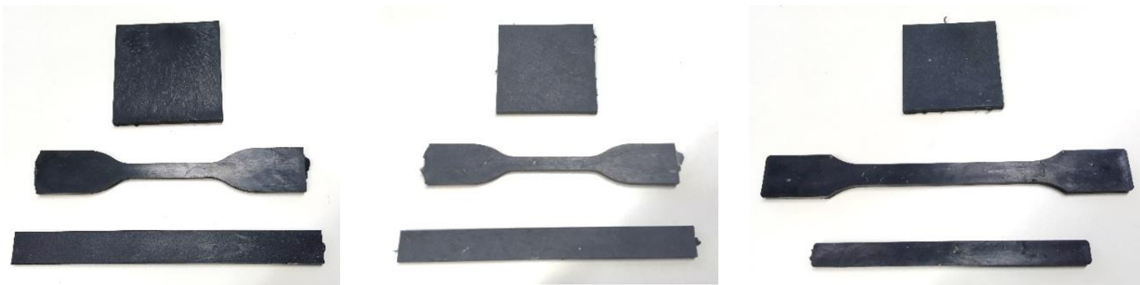
3.1. Stimuli

For the purpose of this study, three particular recyclates are considered that can be easily differentiated and that serve as exemplary post-consumer recycled plastics as they are currently collected in large quantities. We focus on post-consumer plastic waste materials that are processed and recycled 'as is', which means that no additives nor compatibilizers are added to improve processing or technical properties. Together with the industrial partners, it was agreed to focus on two material streams that are very common, both in virgin and in recycled version, since good use of these large-quantity waste streams has the greatest potential impact on aiming for a more circular production. For this study, two different material sources are selected: mixed polyolefins (MPO: the 'floating' fraction in the recycling process) versus recycled Acrylonitrile-butadiene-styrene (rABS) from specific collection fractions. From a technical perspective, these two material groups are very different, e.g., mixed polyolefins (MPO) are flexible and rABS is brittle. From a sensorial perspective, MPO has a grey color with visual contaminations or 'speckles' while rABS is black and smooth. To address the potential effect of color in meaning creation, black color is added to the MPO material to generate a third material stimulus set:

- Material 1: post-consumer recycled mixed polyolefins (MPO grey) mainly containing polyethylene (PE) and polypropylene (PP).

- Material 2: post-consumer recycled mixed polyolefins (MPO black) mainly containing polyethylene (PE) and polypropylene (PP), darkened with black color additives.
- Material 3: post-consumer recycled acrylonitrile-butadiene-styrene (rABS) originating from end-of-life vehicles (ELV) and waste electrical and electronic equipment (WEEE).

Karana [37] states that "materials have a history, which helps us to assign meanings to them even when they are not embodied in products". Therefore, a standardized and equal stimulus set is created for three types of recycled plastics, through injection molding, in an attempt to minimize function or context-bound effects, and to generalize meaning creation. Similar material stimuli are also used in various experiential studies found in literature [10,47–49]. This stimulus set of each material consists of a bar, a doggy bone and a flat square, as visualized in Figure 1. Each material stimulus is labeled with the numbers shown above (with three forms within each material stimulus set). Consequently, participants are not able to associate the materials to their virgin origins, neither does the shape suggest any specific (past) usage or functionality. Since the used injection molding technique delivers very consistent samples, an individual stimulus set is provided for each participant, allowing them to bend or break their samples first-hand.



(a) (b) (c)

Figure 1. Stimulus sets of the materials used in the study: (**a**) rABS; (**b**) MPO grey; (**c**) MPO black.

3.2. Participants

In this study, the targeted stakeholder groups (material engineers and designers) are represented by master students to aim for as little prejudices as possible concerning the technical application of the materials. In total, 60 students aged 21 to 29 participated in the study (average age 23 years). The participants (n = 60, 43 males, 17 females) were recruited among master students during material related courses from both an engineering and a product development department at two universities in Flanders, one of the Belgian regions: material engineers from the Department of Materials, Textiles and Chemical Engineering at Ghent University (n = 30, 25 males, 5 females) and designers from the Department of Product Development at Antwerp University (n = 30, 18 males, 12 females). Using master students as participants increases the comparability in background as they already had the same training during their three bachelor years. Moreover, as they lack professional experience, they are not yet 'biased' by prejudices in industry that might limit the translation to real-life applications. Given the male majority among the engineering students, no equal gender distribution was achieved, however, this might also be a correct reflection of an industrial context.

3.3. Procedure

We conducted two sessions, one at the engineering department and one at the design department, during the same week. Both groups of participants (engineers and designers) followed the same procedure. The study took approximately 15–20 min for each participant and was conducted individually in a classroom. Each participant was given three stimulus sets (i.e., three forms for each of the three recycled materials), as described in the 'Stimuli' section and shown in Figure 1. The three stimulus sets were provided simultaneously, in order to facilitate the evaluation by comparing the three materials. Participants were instructed to evaluate the stimuli using all their senses (sight, touch, smell, hearing), except for taste since the recycled plastics are not food grade. Each material was assessed overall by means of its three forms together.

3.4. Measures

We utilized the lists of seventeen sensorial attributes seventeen interpretive characteristics, based on the frameworks discussed in the 'Framework' section. Drawing upon the principles of recent similar research [45], participants had to complete an evaluation sheet comprising a list of five-point bipolar semantic differential scales (−2, −1, 0, 1, 2) linked to the thirty-four characteristics, and shown in Appendix B. Only the participant's perception of these experiential qualities (sensorial attributes and interpretive characteristics) was studied, independent from application. Thus, in total, 102 scores were collected per participant (34 scores × 3 materials). In addition, their age, gender and study background were requested.

First, for each material, the prominent material characteristics (experiential qualities) are determined by means of One-Sample T tests (RQ1). Second, the significant differences between the three materials are determined by means of Paired-Samples T tests (RQ2). Third, the level of agreement among designers, among engineers and among the total respondent group, is assessed by means of calculating the standard deviations for each of the material characteristics per material (RQ3.1), while the significant differences between designers and engineers on the scores of the material characteristics of each material are calculated by means of Independent-Samples T Tests (RQ3.2).

4. Results

The mean scores and standard deviations for each material on each of the criteria, for the two stakeholder groups and for the entire group of 60 respondents are given in Appendix C. The analyses are discussed below.

4.1. Prominent Characteristics of Each Material

This section explores which sensorial attributes and interpretive characteristics are most defining for each material (RQ1). Therefore, the sensorial and interpretive scales are analyzed statistically by means of One-Samples T Tests for each material in order to identify which of the scores are significantly different from the 'neutral point' (Test Value = 0). For each material, this test is calculated overall, and for designers and engineers individually.

4.1.1. Prominent Characteristics of the rABS Material

The results for rABS are shown in Table 1 and ordered according to the total significance levels (designers and engineers combined). As mentioned before, the attribute of Transparency serves as our control variable, assuming all respondents would score all materials as very opaque. Logically, this attribute is located on top of the list. Moreover, of the 21 significant characteristics, sensorial attributes (13 counts) are found as more prominent characteristics than interpretive characteristics (eight counts). When focusing only on designers or on engineers, 20 significant characteristics were found within each group.

According to the total group of respondents, rABS is considered a material with the following most 'defining' sensorial attributes ($p < 0.05$): Opaque, Colorless, Hard, Low elasticity, Stiff, Intense color, Tough, Odorless, Shrill acoustics, Smooth texture, Brittle, Scratch resistant, Light and with the following interpretive characteristics: Aloof, Formal, Mature, Elegant, Ordinary, Honest, Aggressive, and Futuristic.

Table 1. Mean differences and Significance levels for One-Samples T Tests of rABS material.

Material Characteristic	Level	Designers	Engineers	Total
Sensorial vs. Interpretive		**Mean Diff. (Sign.)**	**Mean Diff. (Sign.)**	**Mean Diff. (Sign.)**
Transparency (opaque–transparent)	S	**−1.90 (<0.000)**	**−1.96 (<0.000)**	**−1.93 (<0.000)**
Colorfulness [1] (colorless–colorful)	S	**−1.20 (<0.000)**	**−1.71 (<0.000)**	**−1.45 (<0.000)**
Softness (hard–soft)	S	**−1.45 (<0.000)**	**−1.18 (<0.000)**	**−1.32 (<0.000)**
Elasticity [1] (low–high)	S	**−1.50 (<0.000)**	**−0.89 (<0.000)**	**−1.21 (<0.000)**
Stiffness (stiff–flexible)	S	**−1.40 (<0.000)**	**−0.96 (<0.000)**	**−1.19 (<0.000)**
Color intensity (weak–intense)	S	**1.00 (<0.000)**	**1.04 (<0.000)**	**1.02 (<0.000)**
Ductility [1] (tough–ductile)	S	**−1.20 (<0.000)**	**−0.63 (0.014)**	**−0.93 (<0.000)**
Odor (odorless–fragrant)	S	**−1.20 (<0.000)**	**−0.68 (0.009)**	**−0.95 (<0.000)**
Cozy–aloof [1]	I	**1.23 (<0.000)**	0.36 (0.057)	**0.81 (<0.000)**
Formal–informal	I	**−0.90(<0.000)**	**−0.61 (0.009)**	**−0.76 (<0.000)**
Acoustics [1] (soft–shrill)	S	**1.28 (<0.000)**	0.25 (0.229)	**0.77 (<0.000)**
Mature–youthful [1]	I	**−0.90 (<0.000)**	**−0.36 (0.022)**	**−0.64 (<0.000)**
Texture (smooth–rough)	S	**−0.53 (0.007)**	**−0.79 (0.001)**	**−0.66 (<0.000)**
Brittleness (brittle–unbreakable)	S	**−0.70 (0.001)**	−0.39 (0.102)	**−0.55 (0.001)**
Scratchability [1] (scratchable–scratch resistant)	S	**0.90 (<0.000)**	0.11 (0.621)	**0.51 (0.002)**
Elegant–vulgar	I	−0.43 (0.062)	**−0.36 (0.015)**	**−0.40 (0.004)**
Weight [1] (light–heavy)	S	−0.13 (0.580)	**−0.79 (<0.000)**	**−0.45 (0.007)**
Ordinary–strange [1]	I	**−0.77 (<0.000)**	−0.07 (0.779)	**−0.43 (0.01)**
Honest–deceptive	I	−0.27 (0.174)	**−0.41 (0.019)**	**−0.33 (0.011)**
Aggressive–calm	I	−0.27 (0.293)	**−0.58 (0.005)**	**−0.41 (0.012)**
Futuristic–nostalgic	I	−0.27 (0.211)	**−0.46 (0.025)**	**−0.36 (0.014)**
Frivolous–sober	I	**0.50 (0.019)**	0.07 (0.738)	0.29 (0.052)
Strength (weak–strong)	S	**0.55 (0.030)**	0.04 (0.866)	0.30 (0.071)
Greasiness (dry–oily)	S	−0.24 (0.316)	−0.36 (0.143)	−0.30 (0.078)
Sexy–not sexy	I	0.00 (1.000)	**−0.61 (0.017)**	−0.29 (0.078)
Toy-like–professional	I	**0.48 (0.041)**	0.04 (0.889)	0.26 (0.129)
Temperature (cold–warm)	S	−0.10 (0.586)	**0.39 (0.025)**	0.14 (0.280)
Disposable–lasting [1]	I	**0.53 (0.024)**	−0.21 (0.326)	0.17 (0.290)
Traditional–modern	I	0.00 (1.000)	**0.32 (0.047)**	0.16 (0.303)
Glossiness (matte–glossy)	S	0.07 (0.738)	−0.36 (0.067)	−0.14 (0.322)
Cheap–expensive	I	0.30 (0.130)	−0.07 (0.745)	0.12 (0.411)
Delicate–rugged	I	0.17 (0.510)	0.04 (0.887)	0.11 (0.557)
Classic–trendy [1]	I	−0.27 (0.265)	**0.44 (0.031)**	0.07 (0.663)
Masculine–feminine [1]	I	−0.37 (0.078)	0.29 (0.200)	−0.05 (0.736)

Note: Significant mean differences in bold. [1] Significant difference between designers and engineers (according to Appendix D).

4.1.2. Prominent Characteristics of the MPO Grey Material

The results for MPO grey are shown in Table 2 and again ordered according to the total significance levels, with again Transparency on top. Of the 21 significant characteristics, sensorial attributes (13 counts) are found more prominent than interpretive characteristics (8 counts). However, for this material more significantly prominent characteristics are found for designers (20 counts) than for engineers (16 counts). According to the total group of respondents, MPO grey is considered a material with the following sensorial attributes ($p < 0.05$): Opaque, Matte, Ductile, Weak color, Unbreakable, Soft acoustics, Light, Scratchable, Dry, Strong, Rough, Fragrant, Warm and with the following interpretive characteristics: Cheap, Not sexy, Toy-like, Vulgar, Informal, Disposable, Rugged, and Calm.

Table 2. Mean differences and Significance levels for One-Samples T Tests of MPO grey material.

Material Characteristic	Level	Designers	Engineers	Total
Sensorial vs. Interpretive		**Mean Diff. (Sign.)**	**Mean Diff. (Sign.)**	**Mean Diff. (Sign.)**
Transparency (opaque–transparent)	S	**−1.93 (<0.000)**	**−1.97 (<0.000)**	**−1.95 (<0.000)**
Glossiness (matte–glossy)	S	**−1.43 (<0.000)**	**−1.1 (<0.000)**	**−1.27 (<0.000)**
Ductility (tough–ductile)	S	**0.97 (<0.000)**	**1.29 (<0.000)**	**1.12 (<0.000)**
Cheap–expensive	I	**−1.10 (<0.000)**	**−1.03 (<0.000)**	**−1.07 (<0.000)**
Color intensity [1] (weak–intense)	S	**−1.17 (<0.000)**	**−0.55 (0.011)**	**−0.86 (<0.000)**
Brittleness (stiff–flexible)	S	**1.00 (<0.000)**	**1.07 (<0.000)**	**1.03 (<0.000)**
Acoustics (soft–shrill)	S	**−1.07 (<0.000)**	**−0.79 (<0.000)**	**−0.93 (<0.000)**
Sexy–not sexy	I	**0.87 (<0.000)**	**0.83 (<0.000)**	**0.85 (<0.000)**
Weight [1] (light–heavy)	S	**−0.53 (0.027)**	**−1.24 (<0.000)**	**−0.88 (<0.000)**
Toy-like–professional	I	**−0.67 (0.004)**	**−0.66 (0.001)**	**−0.66 (<0.000)**
Scratchability (scratchable–scratch resistant)	S	**−0.66 (0.004)**	**−0.76 (0.003)**	**−0.71 (<0.000)**
Greasiness (dry–oily)	S	**−0.80 (<0.000)**	**−0.59 (0.021)**	**−0.69 (<0.000)**
Elegant–vulgar	I	**0.67 (0.002)**	**0.41 (0.026)**	**0.54 (<0.000)**
Formal–informal	I	**0.80 (0.002)**	0.39 (0.118)	**0.60 (0.001)**
Disposable–lasting	I	**−0.63 (0.011)**	**−0.55 (0.040)**	**−0.59 (0.001)**
Delicate–rugged	I	**0.63 (0.002)**	0.24 (0.182)	**0.44 (0.001)**
Strength (weak–strong)	S	**0.71 (<0.000)**	0.21 (0.352)	**0.46 (0.002)**
Aggressive–calm	I	**0.47 (0.032)**	0.31 (0.071)	**0.39 (0.005)**
Texture [1] (smooth–rough)	S	**0.77 (<0.000)**	−0.17 (0.326)	**0.31 (0.017)**
Odor (odorless–fragrant)	S	0.17 (0.444)	**0.55 (0.013)**	**0.36 (0.021)**
Temperature (cold–warm)	S	0.37 (0.078)	0.21 (0.326)	**0.29 (0.049)**
Softness (hard–soft)	S	0.23 (0.282)	0.31 (0.142)	0.27 (0.070)
Stiffness (stiff–flexible)	S	0.17 (0.484)	0.41 (0.076)	0.29 (0.081)
Futuristic–nostalgic	I	0.43 (0.062)	0.00 (1.000)	0.22 (0.102)
Masculine–feminine	I	−0.23 (0.269)	−0.21 (0.227)	−0.22 (0.102)
Mature–youthful	I	0.40 (0.090)	0.03 (0.846)	0.22 (0.135)
Colorfulness [1] (colorless–colorful)	S	0.13 (0.601)	**−0.66 (0.008)**	−0.25 (0.156)
Traditional–modern [1]	I	**0.47 (0.032)**	−0.17 (0.232)	0.15 (0.253)
Honest–deceptive	I	−0.23 (0.387)	−0.07 (0.730)	−0.15 (0.360)
Classic–trendy	I	0.34 (0.086)	−0.14 (0.355)	0.10 (0.410)
Ordinary–strange	I	0.43 (0.085)	−0.21 (0.352)	0.12 (0.482)
Frivolous–sober	I	−0.10 (0.688)	0.24 (0.199)	0.07 (0.663)
Cozy–aloof	I	−0.17 (0.531)	0.24 (0.326)	0.03 (0.851)
Elasticity (low–high)	S	−0.23 (0.452)	0.28 (0.293)	0.02 (0.933)

Note: Significant mean differences in bold. [1] Significant difference between designers and engineers (according to Appendix D).

4.1.3. Prominent Characteristics of the MPO Black Material

The results for MPO black are shown in Table 3 and ordered according to the total significance levels, with again Transparency on top. For this material, only fifteen significant characteristics are found, with more prominent sensorial attributes (11 counts) than interpretive characteristics (4 counts). MPO black is considered a material with the following sensorial attributes ($p < 0.05$): Opaque, Smooth, Ductile, Light, Soft acoustics, Unbreakable, Greasy, Scratchable, Color intense, Glossy, Colorless and with the following interpretive characteristics: Cheap, Not sexy, Toy-like, and Disposable.

Table 3. Mean differences and Significance levels for One-Samples T Tests of MPO black material.

Material Characteristic	Level	Designers	Engineers	Total
Sensorial vs. Interpretive		**Mean Diff. (Sign.)**	**Mean Diff. (Sign.)**	**Mean Diff. (Sign.)**
Transparency (opaque–transparent)	S	**−1.86 (<0.000)**	**−1.96 (<0.000)**	**−1.91 (<0.000)**
Texture (smooth–rough)	S	**−1.43 (<0.000)**	**−1.39 (<0.000)**	**−1.41 (<0.000)**
Ductility (low–high)	S	**1.00 (<0.000)**	**1.07 (<0.000)**	**1.03 (<0.000)**
Weight [1] (light–heavy)	S	**−0.53 (0.011)**	**−1.11 (<0.000)**	**−0.81 (<0.000)**
Acoustics (soft–shrill)	S	**−0.80 (0.001)**	**−1.00 (<0.000)**	**−0.90 (<0.000)**
Cheap–expensive	I	−0.43 (0.068)	**−0.81 (<0.000)**	**−0.61 (<0.000)**
Brittleness [1] (brittle–unbreakable)	S	**0.87 (<0.000)**	0.22 (0.364)	**0.56 (0.001)**
Greasiness [1] (dry–oily)	S	**1.20 (<0.000)**	−0.25 (0.257)	**0.50 (0.002)**
Scratchability (scratchable–scratch resistant)	S	**−0.62 (0.013)**	−0.39 (0.141)	**−0.51 (0.005)**
Sexy–not sexy	I	0.33 (0.143)	**0.48 (0.025)**	**0.40 (0.009)**
Toy-like–professional	I	−0.47 (0.065)	−0.41 (0.086)	**−0.44 (0.011)**
Color intensity (weak–intense)	S	**0.50 (0.009)**	0.29 (0.293)	**0.40 (0.015)**
Disposable–lasting	I	−0.17 (0.493)	**−0.67 (0.003)**	**−0.40 (0.016)**
Glossiness (matte–glossy)	S	0.48 (0.050)	0.29 (0.212)	**0.39 (0.020)**
Colorfulness (colorless–colorful)	S	−0.17 (0.509)	**−0.71 (0.010)**	**−0.43 (0.021)**
Delicate–rugged	I	0.40 (0.090)	0.19 (0.345)	0.30 (0.052)
Stiffness (stiff–flexible)	S	0.23 (0.326)	0.43 (0.083)	0.33 (0.053)
Formal–informal	I	**0.53 (0.027)**	−0.04 (0.839)	0.26 (0.087)
Honest–deceptive	I	−0.33 (0.134)	−0.11 (0.574)	−0.23 (0.124)
Mature–youthful [1]	I	**0.43 (0.035)**	−0.11 (0.502)	0.18 (0.192)
Frivolous–sober	I	−0.27 (0.211)	−0.04 (0.846)	−0.16 (0.268)
Masculine–feminine	I	0.00 (1.000)	−0.30 (0.187)	−0.14 (0.343)
Elegant–vulgar	I	0.07 (0.778)	0.22 (0.282)	0.14 (0.370)
Odor [1] (odorless–fragrant)	S	**−0.70 (0.004)**	0.43 (0.090)	−0.16 (0.389)
Aggressive–calm [1]	I	0.17 (0.421)	**−0.44 (0.031)**	−0.12 (0.404)
Temperature (cold–warm)	S	−0.03 (0.839)	−0.18 (0.363)	−0.10 (0.410)
Traditional–modern	I	−0.07 (0.769)	**0.30 (0.043)**	0.11 (0.443)
Strength [1] (weak–strong)	S	0.46 (0.062)	−0.22 (0.352)	0.13 (0.463)
Elasticity (low–high)	S	−0.33 (0.134)	0.18 (0.502)	−0.09 (0.616)
Cozy–aloof	I	0.00 (1.000)	0.15 (0.476)	0.07 (0.627)
Softness (hard–soft)	S	−0.13 (0.588)	0.00 (1.000)	−0.07 (0.687)
Classic–trendy	I	0.00 (1.000)	0.04 (0.839)	0.02 (0.896)
Ordinary–strange	I	−0.03 (0.884)	0.00 (1.000)	−0.02 (0.909)
Futuristic–nostalgic [1]	I	0.27 (0.147)	−0.30 (0.058)	0.00 (1.000)

Note: Significant mean differences in bold. [1] Significant difference between designers and engineers (according to Appendix D).

4.2. Significant Differences between Materials

This analysis investigates the significant differences between the three materials from the perspective of the total respondent group first, and from the perspective of the separate stakeholder groups (RQ2).

4.2.1. Significant Differences between Materials According to the Total Group

A Paired-Samples T Test is performed on each characteristic item. The Exact Significances (2-tailed) for each combination of two materials are shown in Table 4, with the bold results indicating differences between two material groups ($p < 0.05$).

Table 4. Means and exact Sig. (2-tailed) for Paired-Samples T Test comparing three materials by the total group.

Test Statistics	**rABS ⇔ MPO Grey Exact. Sig. (2-tailed)**	**rABS ⇔ MPO Black Exact. Sig. (2-tailed)**	**MPO Grey ⇔ MPO Black Exact. Sig. (2-tailed)**	**rABS Mean**	**MPO Grey Mean**	**MPO Black Mean**
Color intensity (weak–intense)	**<0.001**	**0.001**	**<0.001**	1.02	−0.86	0.40
Colorfulness (colorless–colorful)	**<0.001**	**<0.001**	0.269	−1.45	−0.25	−0.43
Glossiness (matte–glossy)	**<0.001**	**0.011**	**<0.001**	−0.14	−1.27	0.39
Transparency (opaque–transparent)	0.568	0.261	0.159	−1.93	−1.95	−1.91
Softness (hard–soft)	**<0.001**	**<0.001**	0.081	−1.32	0.27	−0.07
Texture (smooth–rough)	**<0.001**	**<0.001**	**<0.001**	−0.66	0.31	−1.41
Temperature (cold–warm)	0.541	0.171	**0.043**	0.14	0.29	−0.10
Odor (odorless–fragrant)	**<0.001**	**<0.001**	**0.004**	−0.95	0.36	−0.16
Weight (light–heavy)	**0.024**	**0.048**	0.655	−0.45	−0.88	−0.81
Greasiness (dry–oily)	**0.043**	**<0.001**	**<0.001**	−0.30	−0.69	0.50
Acoustics (soft–shrill)	**<0.001**	**<0.001**	0.748	0.77	−0.93	−0.90
Scratchability (scratchable–scratch resistant)	**<0.001**	**<0.001**	0.233	0.51	−0.71	−0.51
Ductility (tough–ductile)	**<0.001**	**<0.001**	0.917	−0.93	1.12	1.03
Elasticity (low–high)	**<0.001**	**<0.001**	0.536	−1.21	0.02	−0.09
Strength (weak–strong)	0.406	0.444	**0.025**	0.30	0.46	0.13
Stiffness (stiff–flexible)	**<0.001**	**<0.001**	0.478	−1.19	0.29	0.33
Brittleness (brittle–unbreakable)	**<0.001**	**<0.001**	0.051	−0.55	1.03	0.56
Cozy–aloof	**0.002**	**<0.001**	0.790	0.81	0.03	0.07
Elegant–vulgar	**<0.001**	**0.019**	**0.023**	−0.40	0.54	0.14
Futuristic–nostalgic	**0.007**	0.154	0.224	−0.36	0.22	0.00
Toy-like–professional	**<0.001**	**0.004**	0.311	0.26	−0.66	−0.44
Frivolous–sober	0.421	**0.042**	0.123	0.29	0.07	−0.16
Aggressive–calm	**0.002**	0.255	**0.009**	−0.41	0.39	−0.12
Ordinary–strange	**0.036**	0.087	0.557	−0.43	0.12	−0.02
Sexy–not sexy	**<0.001**	**0.005**	**0.002**	−0.29	0.85	0.40
Masculine–feminine	0.458	0.637	0.499	−0.05	−0.22	−0.14
Delicate–rugged	0.151	0.304	0.301	0.11	0.44	0.30
Disposable–lasting	**0.009**	**0.021**	0.382	0.17	−0.59	−0.40
Formal–informal	**<0.001**	**<0.001**	0.146	−0.76	0.60	0.26
Cheap–expensive	**<0.001**	**0.001**	**0.009**	0.12	−1.07	−0.61
Classic–trendy	0.813	0.938	0.583	0.07	0.10	0.02
Traditional–modern	0.935	0.880	0.553	0.16	0.15	0.11
Honest–deceptive	0.399	0.552	0.858	−0.33	−0.15	−0.23
Mature–youthful	**<0.001**	**<0.001**	0.922	−0.64	0.22	0.18
Total sign. Sensorial differences	14	14	7			
Total sign. Interpretive differences	11	9	4			
Total number of sign. differences	**25**	**23**	**11**			

Note: Significant differences between materials in bold.

As expected, most similarities appear between the grey and black version of MPO, since the only objective difference between these two materials is the addition of black pigment. Obviously, this makes the black MPO more color intense than the grey edition. In addition, the pigment increases the experienced glossiness and smoothness of the surface, and appears to have an effect on odor, temperature, greasiness, and oddly on the perceived strength of the material. Regarding the interpretive characteristics, an effect of the black color addition is found for the perception of Elegant-Vulgar, Aggressive-Calm, Sexy-Not sexy, and Cheap-Expensive, i.e., the black MPO version is perceived less vulgar, less cheap, less unsexy and aggressive instead of calm.

When comparing the rABS material to the two MPO variants on a sensorial level, rABS is scored as less colorful but with an intense color (no contamination speckles such as the MPOs), harder, tougher, stiffer, shriller acoustics, more scratch resistant, more brittle, odorless, heavier and less elastic. On an interpretive level, rABS is more aloof, elegant, professional, sexy, lasting, formal, expensive and mature. Against expectations, rABS is not found glossier nor smoother than the black MPO, but is experienced aggressive, ordinary and futuristic in contrast to the calm grey MPO, and sober in contrast to the black MPO.

Overall, most significant differences are found between rABS and the MPO variants (25 and 23 counts), compared to within the MPO materials (11 counts). In addition, in all comparisons, more differences are found on the sensorial level than on the interpretive level.

4.2.2. Significant Differences between Materials According to Designers

Table 5 shows the Exact Significances (2-tailed) of a paired-samples T Tests for each item and for each combination of two materials, according to designers. The bold results indicate differences between two material groups ($p < 0.05$).

Designers detect significant differences between rABS and MPO grey (MPO grey Warmer) and between rABS and MPO black (rABS more Ordinary), but do not show significant differences on certain characteristics between rABS and MPO grey (Weight, Aggressive-Calm), between rABS and MPO black (Glossiness, Odor, Elegant-Vulgar, Sexy-Not sexy, Disposable-Lasting) and between MPO grey and MPO black (Temperature, Strength, Aggressive-Calm).

4.2.3. Significant Differences between Materials According to Engineers

Table 6 shows the exact significances (2-tailed) of a paired-samples T Test for each item and for each combination of two materials, according to engineers. The bold results indicate differences between two material groups ($p < 0.05$).

Engineers detect significant differences between rABS and MPO grey (Traditional MPO grey versus Modern rABS), between rABS and MPO black (Warm rABS versus Cold MPO black, Masculine MPO black versus Feminine rABS) and between MPO grey and MPO black (more Unbreakable MPO grey, Frivolous MPO grey versus Sober MPO black, Traditional MPO grey versus Modern MPO black), but no longer experience significant differences on certain characteristics between rABS and MPO grey (Cozy-Aloof, Futuristic-Nostalgic, Ordinary-Strange, Disposable-Lasting, Mature-Youthful), between rABS and MPO black (Texture, Weight, Greasiness, Scratchability, Brittleness, Cozy-Aloof, Toy-like-Professional, Frivolous-Sober, Disposable-Lasting, Mature-Youthful) and between MPO grey and MPO black (Temperature, Odor, Greasiness, Strength, Elegant-Vulgar, Cheap-Expensive).

When comparing the significant differences detected by designers and by engineers, nine disagreements are found between rABS and MPO grey (Temperature, Weight, Cozy-Aloof, Futuristic-Nostalgic, Aggressive-Calm, Ordinary-Strange, Disposable-Lasting, Traditional-Modern, Mature-Youthful), sixteen between rABS and MPO black (Glossiness, Texture, Temperature, Odor, Weight, Greasiness, Scratchability, Brittleness, Cozy-Aloof, Elegant-Vulgar, Toy-like-Professional, Frivolous-Sober, Ordinary-Strange, Sexy-Not sexy, Masculine-Feminine, Mature-Youthful) and eight between MPO grey and MPO black (Odor, Greasiness, Brittleness, Elegant-Vulgar, Frivolous-Sober, Aggressive-Calm, Cheap-Expensive, Traditional-Modern). These results indicate that most dissimilarities occur when comparing rABS to MPO black.

Table 5. Means and exact Sig. (2-tailed) for Paired-Samples T Test comparing three materials by designers.

Test Statistics	**rABS ⇔ MPO Grey Exact. Sig. (2-tailed)**	**rABS ⇔ MPO Black Exact. Sig. (2-tailed)**	**MPO Grey ⇔ MPO Black Exact. Sig. (2-tailed)**	**rABS Mean**	**MPO Grey Mean**	**MPO Black Mean**
Color intensity (weak–intense)	**<0.001**	**0.019**	**<0.001**	1.00	−1.17	0.50
Colorfulness (colorless–colorful)	**<.001**	**0.002**	0.343	−1.20	0.13	−0.17
Glossiness (matte–glossy)	**<0.001**	0.231	**<0.001**	0.07	−1.43	0.48
Transparency (opaque–transparent)	0.573	0.424	0.161	−1.90	−1.93	−1.86
Softness (hard–soft)	**<0.001**	**<0.001**	0.239	−1.45	0.23	−0.13
Texture (smooth–rough)	**<0.001**	**<0.001**	**<0.001**	−0.53	0.77	−1.43
Temperature (cold–warm)	**<0.001**	**<0.001**	**<0.001**	−0.10	0.37	−0.03
Odor (odorless–fragrant)	**<0.001**	0.110	**<0.001**	−1.20	0.17	−0.70
Weight (light–heavy)	0.195	0.050	1.000	−0.13	−0.53	−0.53
Greasiness (dry–oily)	0.074	**<0.001**	**<0.001**	−0.24	−0.80	1.20
Acoustics (soft–shrill)	**<0.001**	**<0.001**	0.174	1.28	−1.07	−0.80
Scratchability (scratchable–scratch resistant)	**<0.001**	**<0.001**	0.909	0.90	−0.66	−0.62
Ductility (tough–ductile)	**<0.001**	**<0.001**	0.895	−1.20	0.97	1.00
Elasticity (low–high)	**<0.001**	**<0.001**	0.662	−1.50	−0.23	−0.33
Strength (weak–strong)	0.713	0.841	0.148	0.55	0.71	0.46
Stiffness (stiff–flexible)	**<0.001**	**<0.001**	0.769	−1.40	0.17	0.23
Brittleness (brittle–unbreakable)	**<0.001**	**<0.001**	0.573	−0.70	1.00	0.87
Cozy–aloof	**<0.001**	**<0.001**	0.565	1.23	−0.17	0.00
Elegant–vulgar	**0.001**	0.173	**0.042**	−0.43	0.67	0.07
Futuristic–nostalgic	**0.038**	0.115	0.573	−0.27	0.43	0.27
Toy-like–professional	**0.001**	**0.016**	0.527	0.48	−0.67	−0.47
Frivolous–sober	0.129	**0.019**	0.545	0.50	−0.10	−0.27
Aggressive–calm	0.056	0.222	0.300	−0.27	0.47	0.17
Ordinary–strange	**0.001**	**0.033**	0.156	−0.77	0.43	−0.03
Sexy–not sexy	**0.005**	0.316	0.027	0.00	0.87	0.33
Masculine–feminine	0.717	0.250	0.315	−0.37	−0.23	0.00
Delicate–rugged	0.223	0.487	0.394	0.17	0.63	0.40
Disposable–lasting	**0.005**	0.063	0.124	0.53	−0.63	−0.17
Formal–informal	**<0.001**	**<0.001**	0.499	−0.90	0.80	0.53
Cheap–expensive	**<0.001**	**0.018**	**0.023**	0.30	−1.10	−0.43
Classic–trendy	0.091	0.459	0.459	−0.27	0.34	0.00
Traditional–modern	0.178	0.178	0.868	0.00	0.47	−0.07
Honest–deceptive	0.073	0.926	0.842	−0.27	−0.23	−0.33
Mature–youthful	0.766	**0.001**	**<0.001**	−0.90	0.40	0.43
Total sign. Sensorial differences	13	12	6			
Total sign. Interpretive differences	9	7	4			
Total number of sign. differences	**22**	**19**	**10**			

Note: Significant differences between materials in bold.

Table 6. Means and exact Sig. (2-tailed) for Paired-Samples T Test comparing three materials by engineers.

Test Statistics	rABS ⇔ MPO Grey Exact. Sig. (2-tailed)	rABS ⇔ MPO Black Exact. Sig. (2-tailed)	MPO Grey ⇔ MPO Black Exact. Sig. (2-tailed)	rABS Mean	MPO Grey Mean	MPO Black Mean
Color intensity (weak–intense)	**<0.001**	**0.031**	**0.005**	1.04	−0.55	0.29
Colorfulness (colorless–colorful)	**<0.001**	**0.003**	0.587	−1.71	−0.66	−0.71
Glossiness (matte–glossy)	**0.003**	**0.019**	**<0.001**	−0.36	−1.10	0.29
Transparency (opaque–transparent)	- [1]	0.327	- [1]	−1.96	−1.97	−1.96
Softness (hard–soft)	**<0.001**	**<0.001**	0.202	−1.18	0.31	0.00
Texture (smooth–rough)	**0.026**	0.074	**<0.001**	−0.79	−0.17	−1.39
Temperature (cold–warm)	0.200	**<0.001**	**<0.001**	0.39	0.21	−0.18
Odor (odorless–fragrant)	**<0.001**	**0.001**	0.752	−0.68	0.55	0.43
Weight (light–heavy)	**0.031**	0.461	0.490	−0.79	−1.24	−1.11
Greasiness (dry–oily)	0.294	0.892	0.056	−0.36	−0.59	−0.25
Acoustics (soft–shrill)	**0.001**	**<0.001**	0.364	0.25	−0.79	−1.00
Scratchability (scratchable–scratch resistant)	**0.016**	0.131	0.102	0.11	−0.76	−0.39
Ductility (tough–ductile)	**<0.001**	**<0.001**	0.739	−0.63	1.29	1.07
Elasticity (low–high)	**<0.001**	**0.001**	0.670	−0.89	0.28	0.18
Strength (weak–strong)	0.416	0.284	0.094	0.04	0.21	−0.22
Stiffness (stiff–flexible)	**<0.001**	**<0.001**	0.443	−0.96	0.41	0.43
Brittleness (brittle–unbreakable)	**<0.001**	0.173	**0.042**	−0.39	1.07	0.22
Cozy–aloof	0.733	0.435	0.285	0.36	0.24	0.15
Elegant–vulgar	**0.003**	**0.029**	0.313	−0.36	0.41	0.22
Futuristic–nostalgic	0.086	0.877	0.129	−0.46	0.00	−0.30
Toy-like–professional	**0.026**	0.130	0.416	0.04	−0.66	−0.41
Frivolous–sober	0.568	0.718	**0.031**	0.07	0.24	−0.04
Aggressive–calm	**0.007**	0.883	**0.003**	−0.58	0.31	−0.44
Ordinary–strange	0.789	0.908	0.295	−0.07	−0.21	0.00
Sexy–not sexy	**<0.001**	**0.002**	**0.025**	−0.61	0.83	0.48
Masculine–feminine	0.075	**0.038**	1.000	0.29	−0.21	−0.30
Delicate–rugged	0.447	0.459	0.566	0.04	0.24	0.19
Disposable–lasting	0.483	0.183	0.733	−0.21	−0.55	−0.67
Formal–informal	**0.040**	**0.033**	0.131	−0.61	0.39	−0.04
Cheap–expensive	**0.008**	**0.012**	0.215	−0.07	−1.03	−0.81
Classic–trendy	0.060	0.205	0.205	0.44	−0.14	0.04
Traditional–modern	0.040	0.040	1.000	0.32	−0.17	0.30
Honest–deceptive	**0.022**	0.095	0.153	−0.41	−0.07	−0.11
Mature–youthful	0.846	0.106	0.170	−0.36	0.03	−0.11
Total sign. Sensorial differences	13	10	5			
Total sign. Interpretive differences	8	6	3			
Total number of sign. differences	**21**	**16**	**8**			

Note: Significant differences between materials in bold. [1] Standard error of difference was zero.

4.3. Level of Agreement

Next, we aim to answer RQ3.1 to find out which attributes and meanings our participants agree upon; both within the group of material engineers (n = 30) and within the group of designers (n = 30) separately, as well as the agreement within the total group (n = 60). This is done by descriptively assessing the standard deviations for each material characteristic, as a high standard deviation might indicate a lack of agreement within a group of respondents. Table 7 shows the average standard deviations per material characteristic across the three materials, ordered by high to low level of agreement according to the total respondent group, and based on the standard deviations for each criterion across materials (last column).

Table 7. Standard deviation of material characteristics for designers, engineers and total.

Material Characteristic	Level	Designers	Engineers	Total
Sensorial vs. Interpretive		**Average Std. Dev.**	**Average Std. Dev.**	**Average Std. Dev.**
Transparency (opaque–transparent)	S	0.333	0.189	0.274
Ductility (tough–ductile)	S	0.862	0.973	0.950
Texture (smooth–rough)	S	0.821	1.019	0.960
Temperature (cold–warm)	S	0.994	1.003	1.004
Futuristic–nostalgic	I	1.115	0.839	1.010
Color intensity (weak–intense)	S	0.838	1.166	1.027
Mature–youthful	I	1.128	0.857	1.028
Glossiness (matte–glossy)	S	1.076	0.996	1.043
Classic–trendy	I	1.138	0.914	1.055
Cheap–expensive	I	1.089	1.004	1.056
Traditional–modern	I	1.244	0.767	1.060
Elegant–vulgar	I	1.190	0.909	1.062
Acoustics (soft–shrill)	S	0.990	1.104	1.086
Masculine–feminine	I	1.105	1.063	1.096
Aggressive–calm	I	1.212	0.950	1.106
Honest–deceptive	I	1.229	0.975	1.108
Weight (light–heavy)	S	1.211	0.926	1.121
Frivolous–sober	I	1.207	1.029	1.129
Sexy–not sexy	I	1.132	1.115	1.130
Softness (hard–soft)	S	1.184	1.082	1.130
Formal–informal	I	1.122	1.120	1.141
Cozy–aloof	I	1.137	1.105	1.153
Delicate–rugged	I	1.213	1.090	1.155
Brittleness (brittle–unbreakable	S	1.070	1.234	1.160
Stiffness (stiff–flexible)	S	1.223	1.144	1.186
Strength (weak–strong)	S	1.165	1.174	1.200
Greasiness (dry–oily)	S	1.006	1.231	1.201
Toy-like–professional	I	1.243	1.169	1.207
Odor (odorless–fragrant)	S	1.091	1.229	1.211
Scratchability (scratchable–scratch resistant)	S	1.141	1.249	1.211
Colorfulness (colorless–colorful)	S	1.260	1.083	1.213
Ordinary–strange	I	1.205	1.194	1.225
Disposable–lasting	I	1.271	1.195	1.256
Elasticity (low–high)	S	1.197	1.280	1.267
Average of sensorial attributes		1.027	1.064	1.073
Average of interpretive characteristics		1.175	1.017	1.116
Total average		**1.101**	**1.041**	**1.095**

Our control attribute 'Transparency' has the lowest standard deviation: almost everyone scored the materials as very opaque, which in fact they are. This is an indication that participants evaluated the materials attentively. The other lowest standard deviations, and thus highest levels of agreement, are obtained for Ductility, Texture, Temperature, and Futuristic-Nostalgic. By contrast, the highest standard deviations are found for Elasticity, Disposable-Lasting, Ordinary-Strange, Colorfulness, and Scratchability.

The average of the standard deviations for all material characteristics is lower for engineers than for designers, indicating that engineers show a higher overall level of agreement. However, designers show a slightly higher level of agreement on the sensorial attributes than on the interpretive ones.

Additionally, sensorial attributes have a lower average standard deviation (i.e., higher level of agreement). This might reflect the greater difficulty or ambiguity in recognizing and associating meanings to (unknown) materials. In contrast, engineers show a higher agreement on interpretive characteristics. More specifically, the items of Color intensity, Weight, and Traditional-Modern have the largest differences between the standard deviations for designers and engineers, while Temperature, Strength, and Formal-Informal have the smallest differences in level of agreement.

4.4. Differences between Designers and Engineers

Finally, to explore which material characteristics evoked significant differences between designers and engineers (RQ3.2), an Independent Samples T Test is performed for each material separately. Table 8 depicts the means of each material characteristic of each material according to designers and engineers, while the footnote indicates whether the (2-tailed) T Test for Equality of Means was significant (see also Appendix D for all actual significant levels).

Table 8. Means of material characteristics for each material according to designers and engineers.

	rABS		MPO Grey		MPO Black	
	Designers	**Engineers**	**Designers**	**Engineers**	**Designers**	**Engineers**
Color intensity (weak–intense)	1.00	1.04	−1.17 [1,2]	−0.55 [1,2]	0.50 [2]	0.29 [2]
Colorfulness (colorless–colorful)	−1.20 [1,2]	−1.71 [1,2]	0.13 [1]	−0.66 [1]	−0.17	−0.71
Glossiness (matte–glossy)	0.07	−0.36	−1.43	−1.10	0.48	0.29
Transparency (opaque–transparent)	−1.90	−1.96	−1.93	−1.97	−1.86	−1.96
Softness (hard–soft)	−1.45	−1.18	0.23	0.31	−0.13	0.00
Texture (smooth–rough)	−0.53	−0.79	0.77[1]	−0.17 [1]	−1.43	−1.39
Temperature (cold–warm)	−0.10	0.39	0.37	0.21	−0.03	−0.18
Odor (odorless–fragrant)	−1.20 [2]	−0.68 [2]	0.17	0.55	−0.70 [1]	0.43 [1]
Weight (light–heavy)	−0.13 [1,2]	−0.79 [1,2]	−0.53 [1]	−1.24 [1]	−0.53 [1]	−1.11 [1]
Greasiness (dry–greasy)	−0.24 [2]	−0.36 [2]	−0.80	−0.59	1.20 [1,2]	−0.25 [1,2]
Acoustics (soft–shrill)	1.28 [1]	0.25 [1]	−1.07	−0.79	−0.8	−1.00
Scratchability (scratchable–scratch resistant)	0.90 [1]	0.11 [1]	−0.66	−0.76	−0.62	−0.39
Ductility (tough–ductile)	−1.20 [1,2]	−0.63 [1,2]	0.97	1.29	1.00	1.07
Elasticity (low–high)	−1.5 [1]	−0.89 [1]	−0.23 [2]	0.28 [2]	−0.33	0.18
Strength (weak–strong)	0.55	0.04	0.71	0.21	0.46 [1]	−0.22 [1]
Stiffness (stiff–flexible)	−1.40	−0.96	0.17	0.41	0.23	0.43
Brittleness (brittle–unbreakable)	−0.70	−0.39	1.00	1.07	0.87 [1]	0.22 [1]
Cozy–aloof	1.23 [1]	0.36 [1]	−0.17	0.24	0.00	0.15
Elegant–vulgar	−0.43 [2]	−0.36 [2]	0.67	0.41	0.07	0.22
Futuristic–nostalgic	−0.27	−0.46	0.43 [2]	0.00 [2]	0.27 [1]	−0.3 [1]
Toy-like–professional	0.48	0.04	−0.67	−0.66	−0.47	−0.41
Frivolous–sober	0.50	0.07	−0.10 [2]	0.24 [2]	−0.27	−0.04
Aggressive–calm	−0.27 [2]	−0.58 [2]	0.47	0.31	0.17 [1]	−0.44 [1]
Ordinary–strange	−0.77 [1]	−0.07 [1]	0.43	−0.21	−0.03	0.00
Sexy–not sexy	0.00	−0.61	0.87	0.83	0.33	0.48
Masculine–feminine	−0.37 [1]	0.29 [1]	−0.23	−0.21	0.00	−0.30
Delicate–rugged	0.17	0.04	0.63	0.24	0.40	0.19
Disposable–lasting	0.53 [1]	−0.21 [1]	−0.63	−0.55	−0.17	−0.67
Formal–informal	−0.90 [2]	−0.61 [2]	0.80	0.39	0.53	−0.04
Cheap–expensive	0.30	−0.07	−1.10	−1.03	−0.43 [2]	−0.81 [2]
Classic–trendy	−0.27 [1]	0.44 [1]	0.34	−0.14	0.00	0.04
Traditional–modern	0.00 [2]	0.32 [2]	0.47 [1,2]	−0.17 [1,2]	−0.07 [2]	0.30 [2]
Honest–deceptive	−0.27	−0.41	−0.23 [2]	−0.07 [2]	−0.33	−0.11
Mature–youthful	−0.90 [1]	−0.36 [1]	0.40 [2]	0.03 [2]	0.43 [1]	−0.11 [1]

[1] Sign. (2-tailed) for T test for Equality of Means ($p < 0.05$). [2] Equal variances not assumed ($p < 0.05$).

Significance levels lower than 0.05 indicate significant differences in the characteristic's score between designers and engineers. A Levene's Test for Equality of Variances preceded this analysis in order to determine whether equal variances can be assumed or not ($p < 0.05$) to interpret the correct significance levels.

The results show that the rABS material induces the most significant differences ($p < 0.05$) between designers and engineers (12 counts), followed by MPO black (eight counts) and MPO grey (five counts). rABS shows significant differences between the two groups on the characteristics of Colorfulness, Weight, Acoustics, Scratchability, Ductility, Elasticity, Cozy-Aloof, Ordinary-Strange, Masculine-Feminine, Disposable-Lasting, Classic-Trendy and Mature-Youthful. In other words, engineers find rABS more colorless, lighter, feminine, disposable and trendy, while designers find the material softer sounded, more scratch resistant, tougher, less elastic, cozier, more ordinary, masculine, lasting, classic and more mature. MPO grey is perceived significantly different concerning Color intensity, Colorfulness, Texture, Weight and Traditional-Modern, meaning engineers find it colorless, smooth, lighter and traditional in contrast to designers who perceive the material with weaker color intensity, rough and modern. Finally, MPO black is scored significantly different regarding Odor, Weight, Greasiness, Strength, Futuristic-Nostalgic, Aggressive-Calm and Mature-Youthful. Engineers find it fragrant, lighter, dry, weak, futuristic, aggressive and mature, while designers score it odorless, greasy, strong, nostalgic, calm and youthful. The other characteristics do not show significant difference ($p > 0.05$).

5. Discussion

In order to facilitate their application in high-quality products, this study aims to understand the perception of three exemplary post-consumer recycled plastics. We have built upon existing frameworks in the context of Materials Experience to explore meaning creation of materials on the basis of sensorial attributes and interpretive characteristics to gain understanding into the way three specific recycled plastics are perceived by two main industrial stakeholder groups: material engineers and designers. In contrast to previous similar studies, one of the main contributions of this study is the focus on exemplary recycled plastics that are industrially processed and materialized in standard stimuli forms, and assessed by a considerably large participant group by means of standard measure scales. The results show differences and similarities between design and engineering respondents on the appraisal of recycled materials, and indicate which characteristics are most prominent in evaluating the material perception of post-consumer recycled plastics. Moreover, when a transition towards a valuable use of these materials is aimed for, different applications require different characteristics (both technical and experiential). Thus, the results of this study might indicate possible product applications of the three recycled plastics. As it is expected that we evolve to a better collection of plastic waste in the future, the amount of post-consumer recyclates will increase as well. Following this trend, it will be even more important to emphasize the intended material perception in order to differentiate different recycled material streams. Therefore, studies as presented here will have to be carried out repeatedly to facilitate the adoption of post-consumer plastics in meaningful applications, as was also done in previous research on emerging materials that focused on, for example, bioplastics [10] and natural fiber composites [50,51].

5.1. Identity of Recycled Plastics

Although no one-to-one rules exist that guarantee meaning-material relationships, certain patterns and defining characteristics (sensorial attributes and interpretive characteristics) of all three materials are detected, an overview of these trends within the design and engineering respondent group can be found in Figure 2, including the similarities between the recyclates (e.g., as expected, all three materials are evaluated as light and opaque). These insights can initiate future idea generation of high-quality applications. Overall, rABS is described smooth, hard and stiff, but brittle with an elegant, formal and aloof character. Thus, rABS might be an interesting material for office supplies, as such products often require stiffness (e.g., perforator), and a smooth and formal appearance that fits in an office environment. The grey MPO variant is perceived matte, ductile, warm and unbreakable, with a cheap and toy-like but rugged character. Thus, MPO grey might be convenient for outdoor toys and bicycle accessories that require high ductility, weather resistance, and must be/feel unbreakable and rugged. The black MPO edition is described smooth, glossy and unbreakable, however still with a cheap and toy-like character. Thus, MPO black might be suitable for strong fitness or sports equipment, as these products require similar strength properties, but the black color addition allows more high-end impression indoor.

Next, Figure 3 takes a closer look at the sensorial attributes (Smooth-Rough, Matte-Glossy, Weak-Intense color, Dry-Oily, Odorless-Fragrant) and interpretive characteristics (Sexy-Not sexy, Expensive-Cheap, Elegant-Vulgar) that show significant differences between the three recycled materials.

In the context of sustainable perception of recyclates, the semantic pairs of Brittle-Unbreakable and Disposable-Lasting (partly reflecting high-quality perception) are also included, despite no significant differences between the two MPO materials are found for these characteristics. When plotting these characteristics against each other, correlations can be seen between an Expensive/Elegant/Sexy/Lasting look and a Cheap/Vulgar/Not sexy/Disposable look on the various sensorial attributes.

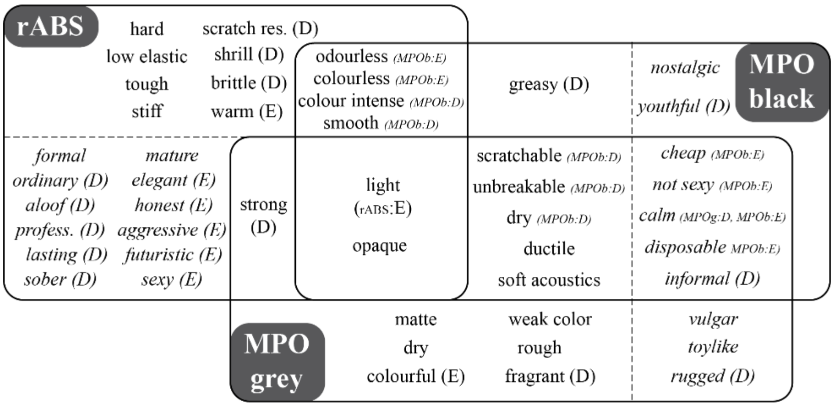


Figure 2. Diagram of defining material characteristics of the three recycled materials, according to designers (D) and engineers (E).

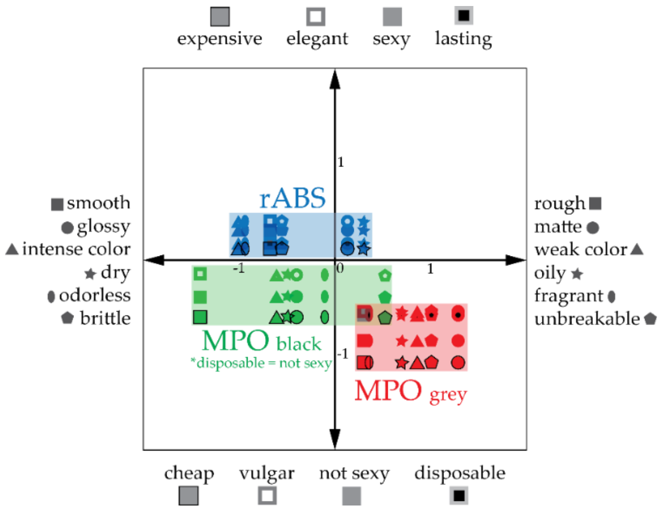


Figure 3. Plot of sensorial attributes and interpretive characteristics for three recycled materials.

This shows that, compared to the others, rABS is perceived as a rather expensive, elegant, sexy and lasting material, which could be attributed to its oily and rather matte look. Moreover, we find a clear difference between the two MPO variants regarding their sensorial attributes. The black color additive even affects several sensorial attributes that should have been the same from a theoretical, technical perspective for both grey and black MPO. A large difference is found concerning the glossiness, texture, odor, and greasiness. A large difference is found concerning the glossiness, texture, odor, and greasiness. However, the black color additive does not appear to be effective enough to completely convert the material perception of MPO to an expensive, elegant, sexy or lasting look. Nevertheless, MPO grey is scored significantly lower than MPO black on these characteristics (except for Disposable-Lasting), which might indicate practical implications for industry and design. In addition, both smoothness and glossiness are actually expected to be the highest for rABS instead of black MPO, based on their technical datasheets. All in all, insights within this graph should be considered when applying these recycled materials in new products. Further research is needed to understand the relation between the interpretive and sensorial characteristics, and the effect of changing specific sensorial attributes on the perception of the interpretive characteristics.

5.2. Differences between Stakeholders

The significant differences between engineers and designers could indicate what material characteristics both stakeholders would not easily agree upon during the design process. The results show that both the amount and the type of significantly different characteristics are very dependent on the material that is evaluated, as only weight induces significant differences for all materials, colorfulness for rABS and MPO grey, and Mature-Youthful for rABS and MPO black. In total, designers and engineers seem to have less significantly different perceptions of interpretive characteristics as compared to sensorial attributes. However, overall as well as in the designer group, the results show a higher level of agreement on sensorial attributes.

We argue that designers in collaboration with material engineers can alter and influence the material perception (e.g., by adding color additives, by in-/decreasing the sorting steps, alternative processing techniques, etc.) to increase valorization and adoption of recycled plastics as sustainable and high-quality materials, as is shown by the contrasting results between the two variants of the MPO material, and by, for example, high standard deviations for Disposable-Lasting (low level of agreement). This raises the question of whether the recycled look of these materials (e.g., speckles in grey MPO in playful outdoor toys) or rather the industrial quality through mass production must be emphasized (e.g., uniform color and glossiness of black MPO in professional fitness accessories)?

5.3. Study Limitations and Further Research

There are limitations to the current study that could inspire further research. In this study, we only use three types of flat injection-molded shapes, presented in an isolated setting to the participants, which is an incomplete approach for such non-technical material explorations. Future research could look into more appropriate forms for material evaluation, such as abstract forms that are more inspiring than flat shapes but do not evoke too many associations with existing products and contexts, or even a set of different types of real products that are materialized in various plastics, to the extent that this is practically feasible.

Next, similar to the education background effect, the influence of gender can be studied as well, but is found not valuable in this context because of the gender imbalance in the engineering respondent group, which is representative for students in this department.

Finally, this paper only focuses on three exemplary recycled materials; rABS, grey MPO, and black MPO. In further research, other recycled plastics should be studied as well, possibly exploring the difference between post-industrial and post-consumer plastics. Although designers and engineers are more familiar with the abstract concept of material samples and might experience fewer difficulties imagining materials in products, it would also be interesting to involve other stakeholders' perceptions as well. Therefore, future research should also replicate the current study to explore the perceptions of recycled materials by end consumers. Additionally, qualitative research techniques, such as interviews or workshops, could be used to develop a more in-depth understanding of the underlying reasons for the perception of recycled materials by engineers, designers and end consumers. This way, next research steps can contribute to further map the material perception of recycled plastics by all stakeholders, and the influence of industrial material alterations on the willingness to design (such as [13]) or on the consumer/user perception (such as [52]). Finally, further research should involve real products as proposed in Section 5.1 and made of recycled plastics, in order to verify whether the expected or intended material perceptions effectively match with the perception of all stakeholders.

6. Conclusions

In conclusion, this paper aims to create an overview pattern based on 60 appraisals to initiate future idea generation for high-quality plastic recycled material applications (material driven design) in a circular economy. It contributes to insights into how these sustainable recyclates can be differentiated on the market by enhancing their experiential qualities in order to address the target users, regardless of their added value from a technical perspective, and to transition towards a valuable use. In practice, industry must not only consider technical properties that are required for application in specific products, but also consider the perception of experiential qualities that is aimed for. Overall, the perception of sensorial attributes and interpretive characteristics varies considerably between the studied recycled materials, which leads to different suitability for specific applications. In addition, substantial similarities between designers and engineers can facilitate the design process when these stakeholders already agree on particular experiential qualities. Therefore, this study suggests possible strategies for the companies involved and underpins the potential of this evaluation method. We propose that, when emphasizing certain desired meanings, designers can facilitate the valorization and adoption of these undervalued materials, first by industry and ultimately by consumers as well.

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Conflicts of Interest: The authors declare no conflict of interest, as the funding industrial partners only provided recycled plastic materials to make stimuli samples, they had no role in the design, execution, interpretation, or writing of the study.

Appendix A

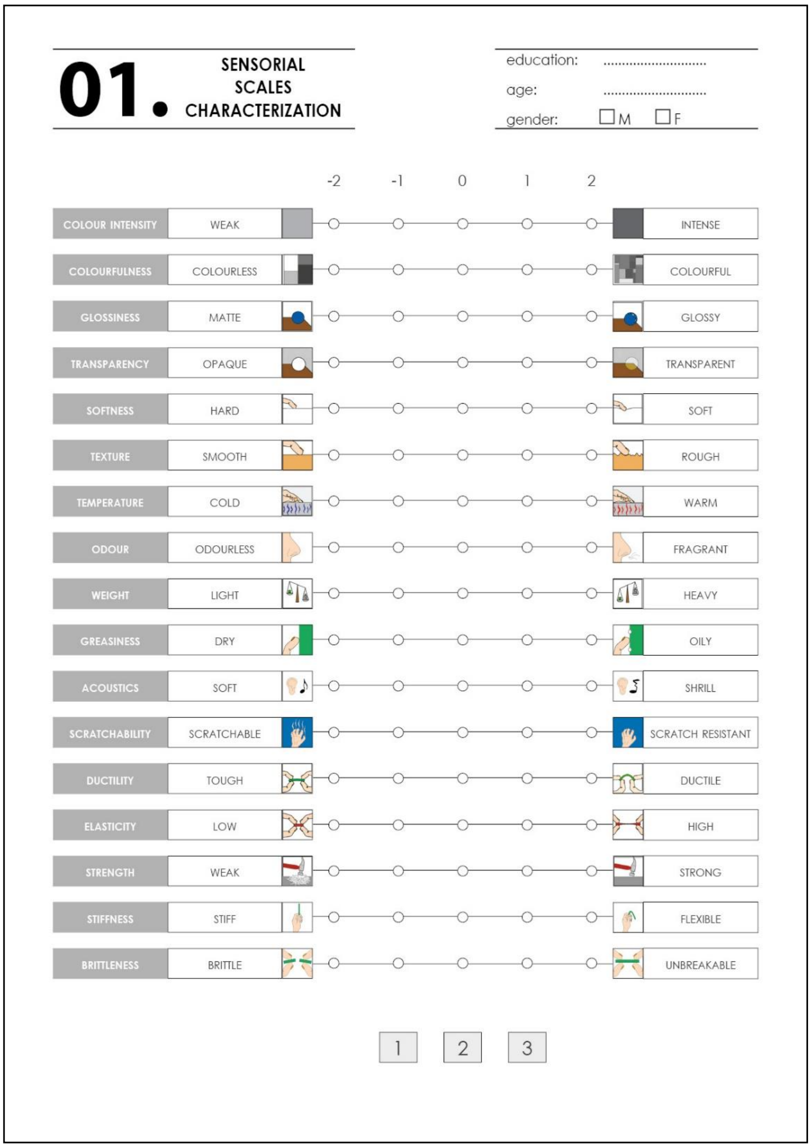
Table A1. Literature Comparison and Selection of Sensorial Attributes for the Main Study.

	List of Sensorial Properties by Van Kesteren, Stappers, de Bruijn, 2007 [46]	Sensorial Scales by Karana, 2009 [37]	List of Sensorial Properties & Manuf. Processes by Karana, Hekkert, Kandachar, 2009 [45]	Selected Sensorial Attributes for the Main Study
Reflection	Reflective–not reflective	Not reflective–reflective	Reflectiveness	Glossiness: Glossy–matte Transparency: Transparent–opaque
	Glossy–matte	Matte–glossy	Glossiness (matteness)	
	Transparent–opaque	Opaque–transparent	Transparency (opaqueness)	
	Not bright–bright Regular–irregular texture			
Color	Hue of color One–many colors			
	Colorless–colorful		Colorfulness	Colorfulness: Colorful–colorless
	Dark–light			
	Durable–faded color		Color intensity	Color intensity: Intense–Weak
	Pattern			
Pressure	Denting–not denting Soft–hard Fast–slow dampening Massive–porous	Hard–soft	Hardness (softness)	Softness: Soft–Hard
Manipulation	Stiff–flexible			Stiffness: Stiff–flexible
	Ductile–tough	Tough–ductile	Ductility	Ductility: Ductile–Tough
	Brittle–tough			Brittleness: Brittle–unbreakable
	Light–heavy	Light–heavy Strong–weak Not elastic–elastic	Weight (lightness) Strength Elasticity	Weight: Light–heavy Strength: Strong–weak Elasticity: High–low Scratchability: Scratchable–scratch resistant

Table A1. *Cont.*

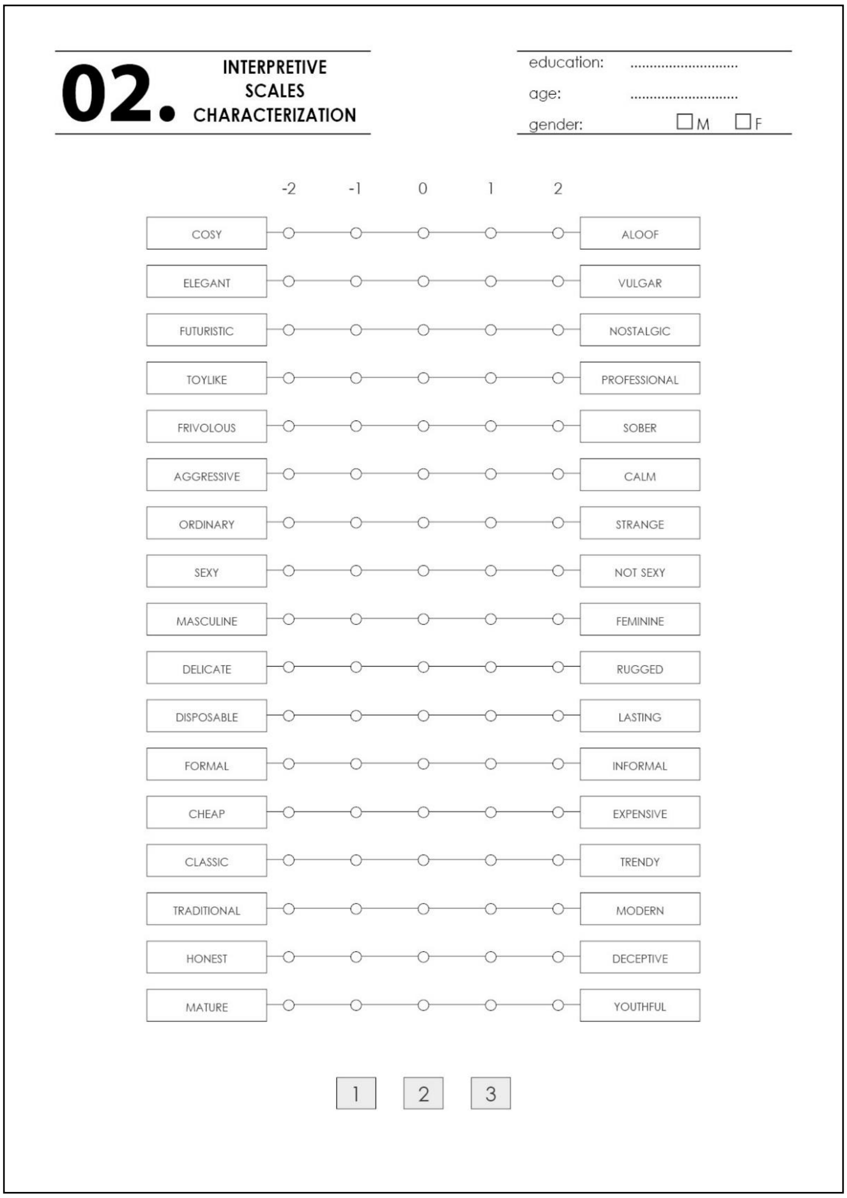
	List of Sensorial Properties by Van Kesteren, Stappers, de Bruijn, 2007 [46]	Sensorial Scales by Karana, 2009 [37]	List of Sensorial Properties & Manuf. Processes by Karana, Hekkert, Kandachar, 2009 [45]	Selected Sensorial Attributes for the Main Study
Friction	Sticky–not sticky Dry–oily Rough–smooth	Smooth–rough	Roughness (smoothness)	Greasiness: Oily–dry Texture: Smooth–rough
Sound	Muffled–ringing Low–high pitch Soft–loud			Acoustics: Soft–shrill
Smell	Natural odor–fragrant Fragrance		Odorous	Odor: Odorless–fragrant
Taste	Flavor			
Temperature	Warm–cold	Cold–warm	Warmth (coldness)	Temperature: Cold–warm
Light radiation	Low–high light emission			

Appendix B



(**a**)

Figure A1. *Cont.*



(**b**)

Figure A1. Evaluation Sheets for the Experiential Evaluations: (**a**) Sensorial Attributes; (**b**) Interpretive Characteristics.

Appendix C

Table A2. Mean & Standard Deviation for Each Material Characteristic, for Each Material, and for Designers, Engineers and Total.

		rABS			MPO grey			MPO black		
		Designers	**Engineers**	**Total**	**Designers**	**Engineers**	**Total**	**Designers**	**Engineers**	**Total**
Color intensity (weak–intense)	Mean	1.00	1.04	**1.02**	−1.17	−0.55	**−0.86**	0.50	0.29	**0.40**
	St. Dev.	0.947	0.999	**0.964**	0.592	1.088	**0.918**	0.974	1.410	**1.199**
Colorfulness (colorless–colorful)	Mean	−1.20	−1.71	**−1.45**	0.13	−0.66	**−0.25**	−0.17	−0.71	**−0.43**
	St. Dev.	1.031	0.659	**0.902**	1.383	1.233	**1.359**	1.367	1.357	**1.378**
Glossiness (matte–glossy)	Mean	0.07	−0.36	**−0.14**	−1.43	−1.10	**−1.27**	0.48	0.29	**0.39**
	St. Dev.	1.100	0.989	**1.060**	0.858	0.817	**0.848**	1.271	1.182	**1.221**
Transparency (opaque–transparent)	Mean	−1.90	−1.96	**−1.93**	−1.93	−1.97	**−1.95**	−1.86	−1.96	**−1.91**
	St. Dev.	0.305	0.189	**0.256**	0.254	0.186	**0.222**	0.441	0.192	**0.345**
Softness (hard–soft)	Mean	−1.45	−1.18	**−1.32**	0.23	0.31	**0.27**	−0.13	0.00	**−0.07**
	St. Dev.	1.055	0.863	**0.967**	1.165	1.105	**1.127**	1.332	1.277	**1.296**
Texture (smooth–rough)	Mean	−0.53	−0.79	**−0.66**	0.77	−0.17	**0.31**	−1.43	−1.39	**−1.41**
	St. Dev.	1.008	1.134	**1.069**	0.728	0.928	**0.951**	0.728	0.994	**0.859**
Temperature (cold–warm)	Mean	−0.10	0.39	**0.14**	0.37	0.21	**0.29**	−0.03	−0.18	**−0.10**
	St. Dev.	0.995	0.875	**0.963**	1.098	1.114	**1.099**	0.890	1.020	**0.949**
Odor (odorless–fragrant)	Mean	−1.20	−0.68	**−0.95**	0.17	0.55	**0.36**	−0.70	0.43	**−0.16**
	St. Dev.	0.887	1.278	**1.115**	1.177	1.121	**1.156**	1.208	1.289	**1.361**
Weight (light–heavy)	Mean	−0.13	−0.79	**−0.45**	−0.53	−1.24	**−0.88**	−0.53	−1.11	**−0.81**
	St. Dev.	1.306	1.031	**1.216**	1.252	0.872	**1.131**	1.074	0.875	**1.017**
Greasiness (dry–greasy)	Mean	−0.24	−0.36	**−0.30**	−0.80	−0.59	**−0.69**	1.20	−0.25	**0.50**
	St. Dev.	1.272	1.254	**1.253**	1.031	1.296	**1.163**	0.714	1.143	**1.188**
Acoustics (soft–shrill)	Mean	1.28	0.25	**0.77**	−1.07	−0.79	**−0.93**	−0.80	−1.00	**−0.90**
	St. Dev.	0.922	1.076	**1.118**	0.923	1.082	**1.006**	1.126	1.155	**1.135**
Scratchability (scratchable–scratch resistant)	Mean	0.90	0.11	**0.51**	−0.66	−0.76	**−0.71**	−0.62	−0.39	**−0.51**
	St. Dev.	1.047	1.133	**1.151**	1.111	1.244	**1.170**	1.265	1.370	**1.311**

Table A2. *Cont.*

		rABS			MPO grey			MPO black		
		Designers	**Engineers**	**Total**	**Designers**	**Engineers**	**Total**	**Designers**	**Engineers**	**Total**
Ductility (tough–ductile)	Mean	−1.20	−0.63	**−0.93**	0.97	1.29	**1.12**	1.00	1.07	**1.03**
	St. Dev.	0.714	1.245	**1.033**	1.129	0.659	**0.938**	0.743	1.016	**0.878**
Elasticity (low–high)	Mean	−1.50	−0.89	**−1.21**	−0.23	0.28	**0.02**	−0.33	0.18	**−0.09**
	St. Dev.	0.731	1.066	**0.951**	1.675	1.386	**1.548**	1.184	1.389	**1.302**
Strength (weak–strong)	Mean	0.55	0.04	**0.30**	0.71	0.21	**0.46**	0.46	−0.22	**0.13**
	St. Dev.	1.298	1.126	**1.235**	0.937	1.177	**1.087**	1.261	1.219	**1.277**
Stiffness (stiff–flexible)	Mean	−1.40	−0.96	**−1.19**	0.17	0.41	**0.29**	0.23	0.43	**0.33**
	St. Dev.	1.102	0.962	**1.051**	1.289	1.211	**1.246**	1.278	1.26	**1.262**
Brittleness (brittle–unbreakable)	Mean	−0.7	−0.39	**−0.55**	1.00	1.07	**1.03**	0.87	0.22	**0.56**
	St. Dev.	1.055	1.227	**1.142**	1.017	1.223	**1.114**	1.137	1.251	**1.225**
Cozy–aloof	Mean	1.23	0.36	**0.81**	−0.17	0.24	**0.03**	0.00	0.15	**0.07**
	St. Dev.	0.858	0.951	**0.999**	1.44	1.300	**1.377**	1.114	1.064	**1.083**
Elegant–vulgar	Mean	−0.43	−0.36	**−0.40**	0.67	0.41	**0.54**	0.07	0.22	**0.14**
	St. Dev.	1.223	0.731	**1.008**	1.061	0.946	**1.006**	1.285	1.05	**1.172**
Futuristic–nostalgic	Mean	−0.27	−0.46	**−0.36**	0.43	0.00	**0.22**	0.27	−0.30	**0.00**
	St. Dev.	1.143	1.036	**1.087**	1.223	0.707	**1.018**	0.980	0.775	**0.926**
Toy-like–professional	Mean	0.48	0.04	**0.26**	−0.67	−0.66	**−0.66**	−0.47	−0.41	**−0.44**
	St. Dev.	1.214	1.347	**1.289**	1.184	0.974	**1.077**	1.332	1.185	**1.254**
Frivolous–sober	Mean	0.50	0.07	**0.29**	−0.10	0.24	**0.07**	−0.27	−0.04	**−0.16**
	St. Dev.	1.106	1.120	**1.124**	1.372	0.988	**1.197**	1.143	0.980	**1.066**
Aggressive–calm	Mean	−0.27	−0.58	**−0.41**	0.47	0.31	**0.39**	0.17	−0.44	**−0.12**
	St. Dev.	1.363	0.945	**1.187**	1.137	0.891	**1.017**	1.136	1.013	**1.113**
Ordinary–strange	Mean	−0.77	−0.07	**−0.43**	0.43	−0.21	**0.12**	−0.03	0.00	**−0.02**
	St. Dev.	1.040	1.331	**1.230**	1.331	1.177	**1.288**	1.245	1.074	**1.157**

Table A2. *Cont.*

		rABS			MPO grey			MPO black		
		Designers	Engineers	Total	Designers	Engineers	Total	Designers	Engineers	Total
Sexy–not sexy	Mean	0.00	−0.61	**−0.29**	0.87	0.83	**0.85**	0.33	0.48	**0.40**
	St. Dev.	1.174	1.257	**1.243**	1.008	1.037	**1.014**	1.213	1.051	**1.132**
Masculine–feminine	Mean	−0.37	0.29	**−0.05**	−0.23	−0.21	**−0.22**	0.00	−0.3	**−0.14**
	St. Dev.	1.098	1.150	**1.161**	1.135	0.902	**1.018**	1.083	1.137	**1.109**
Delicate–rugged	Mean	0.17	0.04	**0.11**	0.63	0.24	**0.44**	0.40	0.19	**0.30**
	St. Dev.	1.391	1.319	**1.345**	0.999	0.951	**0.987**	1.248	1.001	**1.133**
Disposable–lasting	Mean	0.53	−0.21	**0.17**	−0.63	−0.55	**−0.59**	−0.17	−0.67	**−0.40**
	St. Dev.	1.224	1.134	**1.230**	1.273	1.378	**1.315**	1.315	1.074	**1.223**
Formal–informal	Mean	−0.90	−0.61	**−0.76**	0.80	0.39	**0.60**	0.53	−0.04	**0.26**
	St. Dev.	0.845	1.133	**0.997**	1.270	1.286	**1.283**	1.252	0.940	**1.142**
Cheap–expensive	Mean	0.30	−0.07	**0.12**	−1.10	−1.03	**−1.07**	−0.43	−0.81	**−0.61**
	St. Dev.	1.055	1.152	**1.109**	0.960	0.981	**0.962**	1.251	0.879	**1.098**
Classic–trendy	Mean	−0.27	0.44	**0.07**	0.34	−0.14	**0.10**	0.00	0.04	**0.02**
	St. Dev.	1.285	1.013	**1.208**	1.045	0.789	**0.949**	1.083	0.940	**1.009**
Traditional–modern	Mean	0.00	0.32	**0.16**	0.47	−0.17	**0.15**	−0.07	0.30	**0.11**
	St. Dev.	1.365	0.819	**1.136**	1.137	0.759	**1.014**	1.230	0.724	**1.030**
Honest–deceptive	Mean	−0.27	−0.41	**−0.33**	−0.23	−0.07	**−0.15**	−0.33	−0.11	**−0.23**
	St. Dev.	1.048	0.844	**0.951**	1.455	1.067	**1.271**	1.184	1.013	**1.102**
Mature–youthful	Mean	−0.90	−0.36	**−0.64**	0.40	0.03	**0.22**	0.43	−0.11	**0.18**
	St. Dev.	1.062	0.780	**0.968**	1.248	0.944	**1.115**	1.073	0.847	**1.002**

Appendix D

Table A3. Significance Levels (2-tailed) for T Test for Equality of Means for Each Material.

Test Statistics	rABS	MPO Grey	MPO Black
	T Test for Equality of Means Sig. (2-tailed)	T Test for Equality of Means Sig. (2-tailed)	T Test for Equality of Means Sig. (2-tailed)
Color intensity (weak–intense)	0.889	**0.010** [1]	0.507 [1]
Colorfulness (colorless–colorful)	**0.027** [1]	**0.025**	0.132
Glossiness (matte–glossy)	0.130	0.136	0.547
Transparency (opaque–transparent)	0.343	0.581	0.269 [1]
Softness (hard–soft)	0.296	0.796	0.699
Texture (smooth–rough)	0.373	**<0.001**	0.860
Temperature (cold–warm)	0.051	0.581	0.565
Odor (odorless–fragrant)	0.079 [1]	0.204	**0.001**
Weight (light–heavy)	**0.039** [1]	**0.015**	**0.030**
Greasiness (dry–oily)	0.731	0.485	**<0.001** [1]
Acoustics (soft–shrill)	**<0.001**	0.301	0.507
Scratchability (scratchable–scratch resistant)	**0.008**	0.740	0.517
Ductility (tough–ductile)	**0.043** [1]	0.198	0.760
Elasticity (low–high)	**0.014**	0.208 [1]	0.136
Strength (weak–strong)	0.120	0.078	**0.045**
Stiffness (stiff–flexible)	0.115	0.451	0.561
Brittleness (brittle–unbreakable)	0.310	0.814	**0.046**
Cozy–aloof	**0.001**	0.259	0.611
Elegant–vulgar	0.773 [1]	0.339	0.621
Futuristic–nostalgic	0.494	0.101 [1]	**0.020**
Toy-like–professional	0.193	0.968	0.860
Frivolous–sober	0.148	0.277 [1]	0.421
Aggressive–calm	0.322 [1]	0.560	**0.037**
Ordinary–strange	**0.030**	0.055	0.915
Sexy–not sexy	0.062	0.884	0.626
Masculine–feminine	**0.031**	0.922	0.318
Delicate–rugged	0.705	0.129	0.480
Disposable–lasting	**0.019**	0.814	0.124
Formal–informal	0.273 [1]	0.230	0.059
Cheap–expensive	0.205	0.796	0.185 [1]
Classic–trendy	**0.025**	0.052	0.891
Traditional–modern	0.279 [1]	**0.014** [1]	0.176 [1]
Honest–deceptive	0.582	0.622 [1]	0.452
Mature–youthful	**0.032**	0.209 [1]	**0.039**

Note: Significantly equal means in bold. [1] Equal variances not assumed ($p < 0.05$).

References

1. Roth, R.; Field, F.; Clark, J. Materials selection and multi-attribute utility analysis. *J. Comput. Mater. Des.* **1994**, *1*, 325–342. [CrossRef]
2. Rao, R.V.; Davim, J.P.J. A decision-making framework model for material selection using a combined multiple attribute decision-making method. *Int. J. Adv. Manuf. Technol.* **2008**, *35*, 751–760. [CrossRef]
3. Ashby, M.F.; Johnson, K. *Materials and Design: The Art and Science of Material Selection in Product Design*; Elsevier: Oxford, UK, 2012.
4. Geyer, R.; Jambeck, J.R.; Law, K.L. Production, use, and fate of all plastics ever made. *Sci. Adv.* **2017**, *3*, e1700782. [CrossRef] [PubMed]
5. Singh, J.; Ordoñez, I. Resource recovery from post-consumer waste: Important lessons for the upcoming circular economy. *J. Clean. Prod.* **2016**, *134*, 342–353. [CrossRef]
6. Ellen MacArthur Foundation. *Towards the Circular Economy*; McKinsey & Company, Ed.; Ellen MacArthur Foundation: Isle of Wight, UK, 2012.
7. Ordoñez, I.; Rahe, U. Collaboration between design and waste management: Can it help close the material loop? *Resour. Conserv. Recycl.* **2013**, *72*, 108–117. [CrossRef]
8. Geiser, K.; Gros, X.E. Materials matter: Toward a sustainable materials policy. *Electron. Green J.* **2001**, *1*, 479.
9. Freinkel, S. Plastic: A Toxic Love Story. *J. Soc. Hist.* **2013**, *46*, 811–814.
10. Karana, E. Characterization of 'natural' and 'high-quality' materials to improve perception of bio-plastics. *J. Clean. Prod.* **2012**, *37*, 316–325. [CrossRef]

11. European Commission. *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions Closing the loop—An EU Action Plan for the Circular Economy*; European Commission: Brussels, Belgium, 2015.
12. Veelaert, L.; Du Bois, E.; Hubo, S.; Van Kets, K.; Ragaert, K. Design from Recycling. In Proceedings of the EKSIG2017: Alive, Active, Adaptive: International Conference on Experiential Knowledge, Rotterdam, The Netherlands, 19–20 June 2017; pp. 129–143.
13. Sauerwein, M.; Karana, E.; Rognoli, V. Revived Beauty: Research into Aesthetic Appreciation of Materials to Valorise Materials from Waste. *Sustainability* **2017**, *9*, 529.
14. Vezzoli, C. The "Material" Side of Design for Sustainability. In *Materials Experience: Fundamentals of Materials and Design*; Karana, E., Pedgley, O., Rognoli, V., Eds.; Butterworth-Heinemann: Oxford, UK, 2014; pp. 105–121.
15. Ignatyev, I.A.; Thielemans, W.; Vander Beke, B. Recycling of Polymers: A Review. *ChemSusChem* **2014**, *7*, 1579–1593. [CrossRef]
16. Ragaert, K.; Delva, L.; Van Geem, K. Mechanical and chemical recycling of solid plastic waste. *Waste Manag.* **2017**, *69*, 24–58. [CrossRef] [PubMed]
17. Hasling, K.M. Bridging understandings of materials in sustainable product design education. In Proceedings of the Celebration & Contemplation, 10th International Conference on Design & Emotion, Amsterdam, The Netherlands, 27–30 September 2016; pp. 181–190.
18. Bang, A.L.; Buur, J.; Lønne, I.A.; Nimkulrat, N. Tangible Means—Experiential Knowledge Through Materials. In Proceedings of the International Conference 2015 of the Design Research Society Special Interest Group on Experiential Knowledge, Design School Kolding and University of Southern Denmark, Kolding, Denmark, 25–26 November 2015.
19. Karana, E.; Hekkert, P.; Kandachar, P. Material considerations in product design: A survey on crucial material aspects used by product designers. *Mater. Des.* **2008**, *29*, 1081–1089. [CrossRef]
20. Van Kesteren, I.E.H. Selecting Materials in Product Design. Ph.D. Thesis, Delft University of Technology, Delft, The Netherlands, 2008.
21. Veelaert, L.; Du Bois, E.; Ragaert, K.; Hubo, S.; Van Kets, K. Bridging design and engineering in terms of materials selection. In Proceedings of the 7th International Polymers & Moulds Innovations Conference, Ghent, Belgium, 22–23 September 2016; pp. 319–326.
22. Halada, K.; Yamamoto, R. The current status of research and ecomaterials. *MRS Bull.* **2001**, *11*, 871–879. [CrossRef]
23. Schifferstein, H.; Wastiels, L. Sensing materials: Exploring the building blocks for experiential design. In *Materials experience: Fundamentals of Materials and Design*; Karana, E., Pedgley, O., Rognoli, V., Eds.; Butterworth Heinemann: Oxford, UK, 2014; pp. 15–26.
24. Ragaert, K. Trends in Mechanical Recycling of Thermoplastics. Available online: http://hdl.handle.net/1854/LU-7205827 (accessed on 1 March 2020).
25. Ragaert, K.; Hubo, S.; Delva, L.; Veelaert, L.; Du Bois, E. Upcycling of contaminated post-industrial polypropylene waste: A design from recycling case study. *Polym. Eng. Sci.* **2017**. Available online: https://onlinelibrary.wiley.com/doi/abs/10.1002/pen.24764 (accessed on 1 March 2020). [CrossRef]
26. Hubo, S.; Ragaert, K. Evaluation of post-industrial and post-consumer polyolefinbased polymer waste streams for injection moulding. In Proceedings of the 6th Polymers & Mould Innovations International Conference, Guimaraes, Portugal, 10–12 September 2014; pp. 201–206.
27. Huysman, S.; De Schaepmeester, J.; Ragaert, K.; Dewulf, J.; De Meester, S. Performance indicators for a circular economy: A case study on post-industrial plastic waste. *Resour. Conserv. Recycl.* **2017**, *120*, 46–54. [CrossRef]
28. Rognoli, V.; Salvia, G.; Levi, M. The Aesthetic of Interaction with Materials for Design: The Bioplastic's Identity. Available online: https://doi.org/10.1145/2347504.2347540 (accessed on 1 March 2020).
29. Karana, E.; Barati, B.; Rognoli, V.; Zeeuw van der Laan, A. Material Driven Design (MDD): A Method to Design for Material Experiences. Available online: http://www.ijdesign.org/index.php/IJDesign/article/view/1965/693 (accessed on 1 March 2020).
30. Manzini, E. *The Material of Invention*; Arcadia Edizioni: Milan, Italy, 1986.
31. Maine, E.; Probert, D.; Ashby, M. Investing in new materials: A tool for technology managers. *Technovation* **2005**, *25*, 15–23. [CrossRef]

32. Dehn, J. Conception and realization of a sustainable materials library. In *Materials Experience: Fundamentals of Materials and Design*; Karana, E., Pedgley, O., Rognoli, V., Eds.; Butterworth-Heinemann: Oxford, UK, 2014; pp. 155–168.
33. Salvia, G.; Ostuzzi, F.; Rognoli, V.; Levi, M. The value of imperfection in sustainable design: The emotional tie with perfectible artefacts for longer lifespan. In Proceedings of the Sustainability in Design: Now! Challenges and Opportunities fo Design Research, Education and Practice in the XXI Century, Bangalore, India, 29 September–1 October 2011.
34. Karana, E.; Pedgley, O.; Rognoli, V. *Materials Experience: Fundamentals of Materials and Design*, 1st ed.; Butterworth-Heinemann: Oxford, UK, 2013; ISBN 0080993761.
35. Karana, E.; Hekkert, P.; Kandachar, P. A tool for meaning driven materials selection. *Mater. Des.* **2010**, *31*, 2932–2941. [CrossRef]
36. Giaccardi, E.; Karana, E. Foundations of Materials Experience: An Approach for HCI. Available online: https://doi.org/10.1145/2702123.2702337 (accessed on 1 March 2020).
37. Karana, E. Meanings of Material. Ph.D. Thesis, Delft University of Technology, Delft, The Netherlands, 2009.
38. Camere, S.; Karana, E. Experiential characterization of materials: Toward a toolkit. In Proceedings of the International Conference on Design Research Society (DRS), Limmerick, Ireland, 25–28 June 2018.
39. Veelaert, L.; Du Bois, E.; Moons, I.; Karana, E. Experiential characterization of materials in product design: A literature review. *Mater. Des.* **2020**, *190*, 108543. [CrossRef]
40. Lilley, D.; Smalley, G.; Bridgens, B.; Wilson, G.T.; Balasundaram, K. Cosmetic obsolescence? User perceptions of new and artificially aged materials. *Mater. Des.* **2016**, *101*, 355–365. [CrossRef]
41. Bahrudin, F.I.; Aurisicchio, M. 'Is this wallet made of real leaves?': A Study of Sustainable Materials' Emotional Experiences. In Proceedings of the NordDesign 2018, Linköping, Sweden, 14–17 August 2018.
42. Rognoli, V.; Bianchini, M.; Maffei, S.; Karana, E. DIY materials. *Mater. Des.* **2015**, *86*, 692–702. [CrossRef]
43. Karana, E.; Hekkert, P.; Kandachar, P. Assessing material properties on sensorial scales. In Proceedings of the 2009 ASME International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, DETC2009, San Diego, CA, USA, 30 August–2 September 2009; Volume 2, pp. 911–916.
44. Lindberg, S.; Roos, A.; Kihlstedt, A.; Lindström, M. A product semantic study of the influence of the sense of touch on the evaluation of wood-based materials. *Mater. Des.* **2013**, *52*, 300–307. [CrossRef]
45. Karana, E.; Hekkert, P.; Kandachar, P. Meanings of materials through sensorial properties and manufacturing processes. *Mater. Des.* **2009**, *30*, 2778–2784. [CrossRef]
46. Van Kesteren, I.E.H.; Stappers, P.J.; de Bruijn, J.C.M. Materials in Products Selection: Tools for including user-interaction in materials selection. *Int. J. Des.* **2007**, *1*, 41–55.
47. Wastiels, L.; Schifferstein, H.N.J.; Heylighen, A.; Wouters, I. Red or rough, what makes materials warmer? *Mater. Des.* **2012**, *42*, 441–449. [CrossRef]
48. D'Olivo, P.; Del Curto, B.J.; Faucheu, J.; Lafon, D.; Bassereau, J.-F.; Sébastien, L. Sensory Metrology: When Emotions and Experiences Contribute to Design. In Proceedings of the International Conference on Engineering Design, ICED13 (Vol. 7 DS75-07), Seoul, Korea, 19–22 August 2013; pp. 507–516.
49. Hope, A.D.; Jones, M.; Zuo, H. Sensory perception in materials selection for industrial/product design. *Int. J. Des. Objects* **2012**, *6*, 17–31. [CrossRef]
50. Karana, E.; Nijkamp, N. Fiberness, reflectiveness and roughness in the characterization of natural and high quality materials. *J. Clean. Prod.* **2014**, *68*, 252–260. [CrossRef]
51. Rognoli, V.; Karana, E.; Pedgley, O. Natural fibre composites in product design: An investigation into material perception and acceptance. In Proceedings of the DPPI'11—Designing Pleasurable Products and Interfaces, ACM Press, Milan, Italy, 22–25 June 2011.
52. Overvliet, K.E.; Soto-Faraco, S. I can't believe this isn't wood! An investigation in the perception of naturalness. *Acta Psychol. (Amst)* **2011**, *136*, 95–111. [CrossRef]