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Coated Paper-Based Packaging Waste: Investigation on Sensorial Properties Affecting the Material Class Perception

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Abstract: Packaging waste correct sorting hugely impacts fiber-based packaging circularity. Currently, this is more crucial than ever, also due to the increased market share of fiber-based packaging. This study evaluated the relationship between the aesthetic properties and user material sorting actions of lightweight dispersion-coated and uncoated paper substrates. Unlike previous literature, no labeling or graphics were involved in this study, focusing on the physical and aesthetic properties of both coatings and substrates. Untrained panelists participated in a multi-phase (descriptive and hedonic) analysis involving a questionnaire and antonym scales about samples' visual and tactile properties, which were also characterized. The results highlight a remarkable panelist's ability to assess the relative gloss and roughness. Perceived roughness and mattness statistically significantly correlated to cellulosic material identification. Moreover, material sorting into the paper recycling stream was statistically significantly regulated by sample mattness, followed by sample roughness. This work suggests that, without any graphic or textual information, the combination of substrate characteristics and coating formulation strongly impacts the packaging aesthetics, hence packaging perception as paper-based material. Consequently, the correct material identification and sorting can be encouraged by proper packaging materials selection and coating development.

Keywords: fiber-based substrate; sensorial perception; coating; packaging waste; sorting

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1. Introduction

In design practice, when it comes to physical artifacts, practitioners need to face the material side of products. Independently from their intrinsic nature, physical products always challenge designers in the analysis, screening, scouting, and selection activities related to materials and their selection [1]. Traditionally, the material selection practice was mainly driven by the analysis of technical properties. Recently, however, this process evolved, including further discriminant factors. First, aesthetic and hedonic attributes were incorporated [2], as well as material characteristics evoking intangible and experiential meanings of materials [3,4], which are linked to the user's cultural and psychological background. Secondly, sustainability-related material characteristics affecting the whole life cycle of the product were enclosed [5,6]. Such evolution undoubtedly led to an increment of material properties to be considered during the design phase, transforming the material selection process into a complex activity to manage, actively including users.

In short-lifespan products, e.g., packaging and food packaging, the material selection activity is even more crucial, requiring additional considerations. Indeed, the users' misperception of materials can strongly influence the end-of-life treatment of the product, possibly affecting the recycling streams [7]. The intertwining of technical, sensorial, aesthetic, and ethical material properties becomes essential for proper packaging development. Material availability and safety, cost, processability, and recyclability or reusability [8,9] are some of the factors that define the current packaging material selection criteria. Among others, paper and cardboard represent a big share [10]. Recently, fiber-based packaging was put in the spotlight due to recent regulatory decisions on the plastic packaging ban both at the European scale, e.g., the Single-Use Plastic Directive (EU) 2019/904 [11], and at a national one, e.g., Decree No. 2023-478 in France. Nevertheless, it must be acknowledged that fiber-based substrates require functional additives and layers to cope with otherwise poor barrier properties and to sustain the transition from plastic packaging to fiber-based ones.

Traditionally, extrusion-coated and laminated substrates represent the main functionalizing technologies on the market for the improvement of paper/cardboard packaging solutions. More recently, dispersion coatings raised the interest of the industry with the promise of similar properties at a lower non-cellulosic content. This might help in achieving higher recycling yields at a paper mill. Multiple studies reported interesting properties under both barrier and processing [12–16] properties.

Packaging developers are, therefore, called to interpret and deploy fiber-based materials into packaging applications without compromising the functionality of the products, their appeal, and their end-of-life treatment.

Several European bodies provided packaging designers with best practices and guidelines to improve the guidance on the effects of design choices on packaging recyclability [17–20]. Consumers' role is crucial when it comes to the conferring of packaging in the proper disposal stream, and their actions are driven by a series of different factors, ranging from socio-cultural topics up to regulatory and marketing ones [21]. Previous studies reported how the sorting behavior is an unconscious process determined by habits [22]. Among the theories developed and addressed in former literature concerning consumers' behavior, it is possible to recall the Theory of Reasoned Actions (TRA) and the Theory of Planned Behavior (TPB) [23–26]. The TRA and the TPB are closely linked, with the TPB being a conceptual extension of the TRA. Both refer to non-packaging factors related to personal attitudes, perceived behavioral control, and subjective norms that might work as predictors of intentions to engage in the sorting behavior. Undoubtedly, without a correct selection of the recycling stream, valuable fibrous material is not recycled. Additionally, despite environmental labeling [7,27], consumers were reported to rely on material perception and knowledge to make a final decision [28], suggesting that improvements in terms of aesthetic and sensorial packaging features may encourage behavioral engagement [29].

Extensive literature focused on the effect of labels and graphic elements to suggest positive consumer behavior [30–32]. However, it seems that there is a lack of studies specifically focusing on the following for fiber-based packaging solutions: material-coating aesthetic properties, consumer material perception and identification, and subsequent correct household packaging waste sorting.

Based on previous statements, this study aimed to investigate the effects that the visual and tactile properties of materials have on the specific selection of the stream where fiber-based packaging waste is sorted.

Although previous studies [33] tried to explore similar topics on the cultural level for packaging designers, a specific reflection on material sensorial properties and their influence on the specific selection for the recycling stream is missing. Therefore, it was essential for researchers to conduct some tests involving both participants and physical material samples in structured tests [3]. In this work, the authors explored the actual consumer material perception of dispersion-coated paper-based packaging materials through a panel test. Both descriptive and hedonic sensory tests were involved in the present study. The investigation aimed to provide a first attempt to understand the existing relationship between aesthetic and sensorial features of coated fiber-based packaging. Moreover, the investigation excluded any possible labeling, text, or graphics as a possible influencing factor. Consequently, information about the sensorial guidance for correct consumer behavior through coating aesthetic design is provided here.

2. Materials and Methods

2.1. Materials

Three different paper substrates were involved in the study, to reproduce a matrix of different aesthetic results in the samples:

- Mondi (Weybridge, UK) ProVantage Kraftliner, a 125 g/m^2, 187 ± 2 μm thick virgin kraftliner (KK)
- Mondi (Weybridge, UK) ProVantage Komiwhite, a 125 g/m^2, 146 ± 1 μm thick white top kraftliner (KB)
- MetsäBoard (Espoo, Finland) MetsäBoard Pro WKL, a 145 g/m^2, 142 ± 2 μm thick double-coated white top kraftliner (KP)

In addition to uncoated (UC) substrates, two different polymeric coating formulations were applied to the above-mentioned substrates:

- H39K 60, containing 60% dry weight of highly crosslinked styrene–butadiene and 40% dry weight of platy kaolin. Aqueous dispersion formulation is described elsewhere [14]. In this work, the coating will be referred to as "Exp".
- SA-B, a styrene acrylate commercial barrier dispersion coating. In this work, such coating will be referred to as "Comm".

Both Exp and Comm coatings were discussed in terms of barrier and processing in the authors' previous research [12,14]. A total of nine different samples were realized for the analysis of the interaction in the user test.

Sample Production

Before coating application and drying, aqueous dispersions were stirred with a magnetic anchor for at least 30 min at 500 rpm. Coating occurred manually with a 12 μm (wet film thickness) Meyer K-bar. Right after coat application, coated substrates were dried at 120 °C for 90 s inside an oven; following that, they were conditioned at 23 ± 1 °C and 50 ± 2% relative humidity for at least 24 h before any further characterization, which included, e.g., dry coat grammage, which was, on average, 9.4 ± 1.5 g/m^2.

A representative image of coated samples is reported in Figure 1.

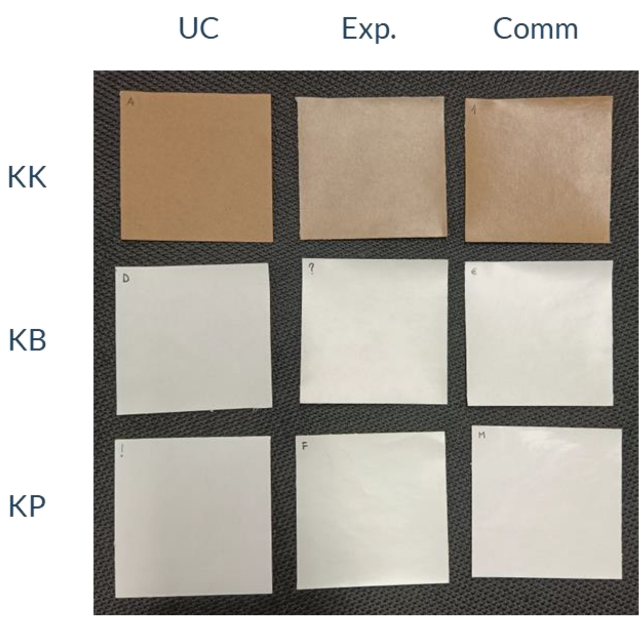


Figure 1. The samples that were provided to the panelists. Each measured 80 × 80 mm.

2.2. Sample Characterization

2.2.1. Water Barrier

The Cobb1800 test, as described in BS EN ISO 535:2014 [34] was performed to determine water absorption of both coated and uncoated samples in triplicate. The environment temperature and relative humidity were kept constant at 23 ± 1 °C and 50 ± 2%, respectively. Due to the specimen dimensions (80 mm × 80 mm), the test area was set to almost 40 cm^2. Higher water absorption is associated with a lower water barrier performance.

2.2.2. Water Vapor Transmission Rate

Water Vapor Transmission Rate (WVTR) was measured in triplicate according to the methodology defined in BS ISO 2528:2017 [35] using cups filled with 35.0 ± 0.1 g of silica gel. The test time depended on actual barrier performance—generally requiring 24−96 h—interrupting it after a minimum of six measurements when the test reached a steady state, or at a mass gain of around 1.2 g. The environment temperature and relative humidity were kept constant at 23 ± 1 °C and 50 ± 2%, respectively. Samples were positioned with the coated side facing into the cup. The test area was almost 20 cm^2. A higher WVTR implies that a sample provides less barrier to moisture.

2.2.3. Grease Barrier

The samples (triplicate measurements) underwent a grease permeability test according to the methodology defined in BS ISO 16532-1:2008 [36], applying a 3 mm thick dyed palm kernel oil on the coated surface. The show-through time was measured by visual observation, setting the maximum test time to 24 h, as defined in the above-mentioned standard. The environment temperature and relative humidity were kept constant at 23 ± 1 °C and 50 ± 2%, respectively. A higher grease permeation time is associated with a higher grease barrier.

2.2.4. Roughness

Both longitudinal (i.e., parallel to the machine direction) and transversal roughness were measured with a UBM (Ettlingen, Germany) Microfocus laser profilometer. The test was carried out according to DIN4768, with 5.6 mm long measurements, whereas the sampling density was 500 points per millimeter. The average Maximum Height of the Profile (RzDIN) was used in this work as the parameter defining the roughness of the samples−RzDIN is the average of five measurements across the measurement length. Both longitudinal (MD) and transversal (CD) data were acquired, i.e., parallel or orthogonal to fiber alignment, respectively. R_zDIN reported in the results is the average of five measurements for each sample.

2.2.5. Relative Gloss

The relative gloss value (RGV) was measured with a portable Konica Minolta CM-2500d (Tokyo, Japan) spectrophotometer, featuring the patented Numerical Gloss Control. The apparatus is equipped with a diffuse illumination and an 8° viewing system. The Konica Minolta CM-2500d determines the RGV as the difference between the Specular Component Included (SCI) and Specular Component Excluded (SCE) spectra. Therefore, the RGVs must not be confused with standard glossiness measurement, since the two cannot be compared. The RGV was included in this work to perform a comparison only among the investigated samples—to be then related to consumers' material family identification. For standard glossiness measurements, other equipment—i.e., light sources, and angles—should be adopted, as defined in specific standards.

For each sample, the RGV was determined as the average of five measurements taken across the surface of the sample.

2.2.6. Static Coefficient of Friction

Coating slipperiness was determined by measuring the static coefficient of friction adopting the methodology defined in ASTM D4918-97 [37]. Despite being developed for uncoated paper substrates, ASTM D4918-97 was used to assess coated paper, too. The dimension of the samples was a minimum of 80 mm × 80 mm. The sled weighed 230 g in total, excluding the weight of the sample.

The inclination of the plane was gradually increased until the sled started to move, and the critical angle was noted. The static coefficient of friction was then calculated as the average tangent of 10 measured angles.

2.3. Sensorial Test

A total of 30 untrained panelists voluntarily participated in the study. The users were recruited among the students enrolled in the Master of Science programs of the School of Design at Politecnico di Milano. They were screened to ensure they were concerned about correct waste sorting. Additionally, the users reported they sort packaging waste at home—regardless of having housemates or living with the respective family—and did not have extensive prior knowledge about sensory panel tests. Panelists' ages ranged from $21-28$ y.o., with an average of 23.8 ± 1.5 y.o.; their gender was equally distributed between males and females; the majority of the participants (93%) were Italian, and the remaining assessors had another nationality. Different from previous research [38], all the panelists were non-experienced users. All of them held a B.Sc. degree.

The sensorial test was developed to be carried out by the panelists at their pace, without any constant supervision. Nevertheless, they were free to ask for doubts about possible procedures to a sensorial test moderator—who was sitting aside them—all along the test duration. The moderator's role was required not to bias panelists' perceptions and opinions; hence, they could only provide information about possible unclear test methodology.

The setup involved a table at the center of a room, with fluorescent light tubes located on the ceiling. A chair was provided; still, the panelists were free to sit, stand up, or alternate according to their will. A first 100 cm × 65 cm corrugated cardboard board was preliminary located on the table. Each participant needed to work on a sequence of three different boards (all measuring 100 cm × 65 cm), as described further on. The user–sample interaction modality was similar to "free exploration", as reported by Veelaert et al. [3]. Due to the nature of the samples and to safeguard sample integrity throughout the test, the interaction was restricted to actions that did not permanently damage the samples. Therefore, forbidden actions included, e.g., tearing and crushing.

The test followed a four-step design, involving increasingly deeper material analysis and awareness, as discussed hereafter (see Appendix A for the full list of questions and possible multiple-choice answers):

1. At first, no board was presented, and the authors asked each participant to fill out an MS Forms questionnaire about general self-perception regarding their attitude towards waste sorting, material identification, and environmental labeling. Such a phase aimed to acquire the data to be then compared to subsequent panelists' choices and determine whether there is a correlation between their perception and actual decisions.
2. Following that, nine squared paper-based samples (see Section 2.1) were provided in a random order alongside a first board (Figure 2a). Samples had an identification character, randomly selected among alphanumerical plus special characters for data acquisition purposes (as visible in Figure 1). The participants were asked to select the recycling bin (i.e., undifferentiated/mixed waste, organic, paper, or plastic) where they would throw each material considering a clean (i.e., no stain or solid residue due to possible content–packaging interaction) packaging made of the material sample they were handling. The situation tried to understand which was the users' behavior when they first came in contact with a new material, or a material with a hidden

or without correct environmental labeling. The material–bin association was then annotated in an MS Forms questionnaire for the subsequent data analysis.

3. Panelists collected the samples and changed the first board with a second one (Figure 2b). At first, users were asked to distribute the samples over an unstructured scale (40 marks). The scale reported antonymous adjective anchors "paper-like" and "other-like" at marks 0 and 40, respectively. "Other-like" is a statement representing any other nature apart from paper. The panelists were then asked to choose among possible attributes that allowed them to identify a material as paper-like or not. Possible options are reported in Appendix A. Following that, panelists had to distribute the samples over a different unstructured scale (40 marks), reporting "low performance" and "high performance" at marks 0 and 40, respectively. Each sample positioning along the scale was identified by its center point location (by construction, marks were 2 cm apart, with samples having 4 mark long sides, i.e., 8 cm, which allowed the authors to easily determine the position of the center). The sorting process aimed to determine which were the perceived barrier properties of the samples to water, moisture, and grease. Therefore, the operation occurred three times in a row, considering different application situations to provide the panelists with an actual application and a reasonable context (the following list was reported in the bottom-left angle of the second board, as of Figure 2b):
    a. Humid/washed vegetables, e.g., carrots and salad to be packed into bags.
    b. Dry fruit, like almonds, nuts, etc. to be packed into pouches.
    c. On-the-go food or ready-meal packages containing greasy foodstuffs, e.g., lasagna and French fries, to be contained in a paper tray.

    Right after this last scaling, panelists were asked again to state attributes that allowed them to identify a material as of high performance.
4. Finally, the analysis reached the deepest level of analysis for the panelists with the third board (Figure 2c). In this step, the panelists were asked to provide visual and tactile perception. In particular, they had to sort the samples over three different unstructured scales (40 marks):
    a. "Rough" vs. "Smooth"
    b. "Matte" vs. "Glossy"
    c. "Resistant" vs. "Slippery"

    placed at marks 0 and 40, respectively. The couples of attributes were provided with icons providing a shared reference about what was classified as, e.g., glossy or slippery. The test concluded with an MS Forms question about the users' perception of possible material coating, to be rated from −2 (Uncoated) up to +2 (Coated).

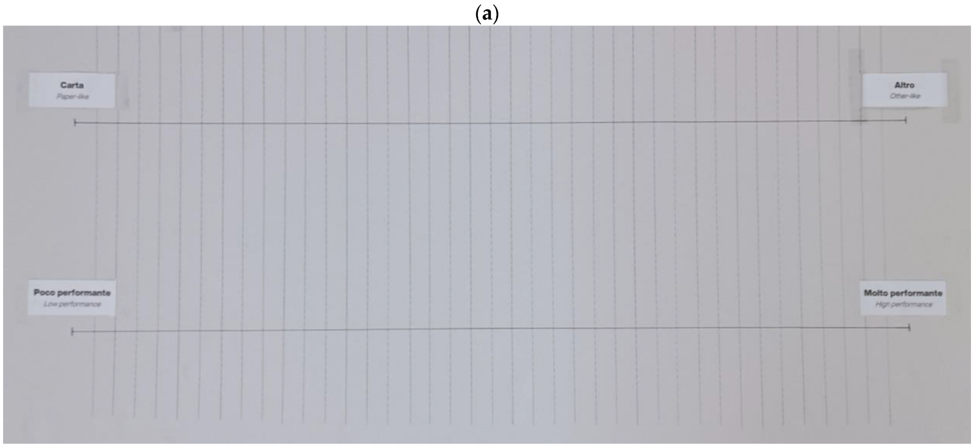
2.4. Data Analysis

Data about barrier properties (i.e., water absorption, WVTR, grease barrier) were normalized along an exponential curve to an average coat thickness of 7 µm, as described in a previous study [14].

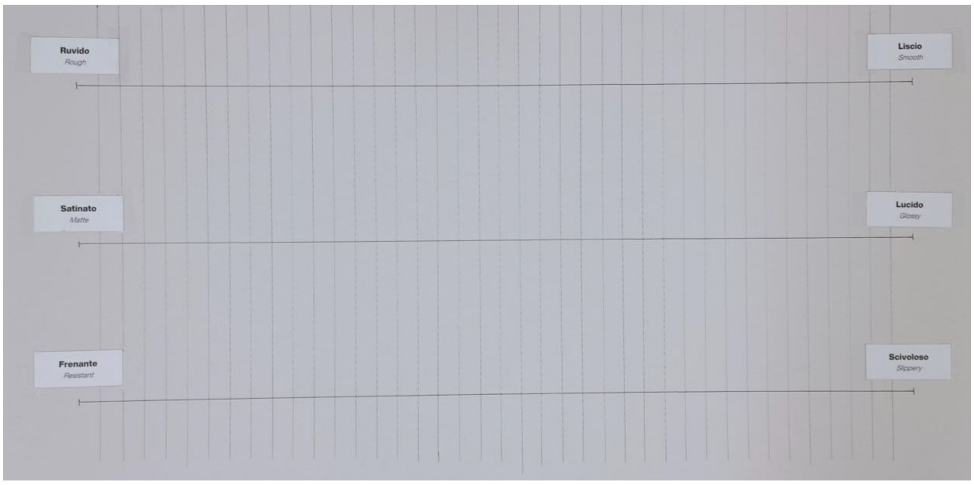
Statistical analysis was performed using Minitab 21.3.1 and MS Excel v. 2310. Whenever data modulation was required, it is stated in the figure legend. Additionally, modulation for each measured barrier property was carried out on panelists' minimum and maximum median values instead of 0 and 40 (i.e., minimum and maximum scale values).

If not stated elsewhere, the graphs about sample characterization include standard deviation error bars.

(**a**)



(**b**)



(**c**)

Figure 2. Representative pictures of the actual boards that were presented to the panelists: (**a**) First board, related to packaging waste sorting—boxes: Plastic; Paper; Organic Waste; Undifferentiated Waste. (**b**) Second board, related to paper-like perception and perceived performance—Scales: Paper-like vs. Other-like; Low Performance vs. High Performance. (**c**) Third and last board, related to visual and tactile properties—Scales: Rough vs. Smooth; Matte vs. Glossy; Resistant vs. Slippery.

3. Results

3.1. Material Characterization

3.1.1. Barrier Properties (Water, Moisture, and Grease Barriers)

Sample barrier properties are reported in Figure 3. As predictable, uncoated substrates provided the worst properties. Compared to Comm, Exp provided the worst water barrier, similar WVTR, yet the best grease barrier. Such performance was already documented and extensively discussed in previous research [14]. The extremely high resistance of KP Exp to grease is due to the normalization process, which, thanks to both a coat thickness lower than 7 µm and the resistance up to 24 h, increased such value to slightly more than 2000 min. Nevertheless, both Exp and Comm provided good-to-high performance improvement, with kaolin filler providing an optimal barrier in terms of grease barrier, yet a poor water barrier due to its hydrophilicity.

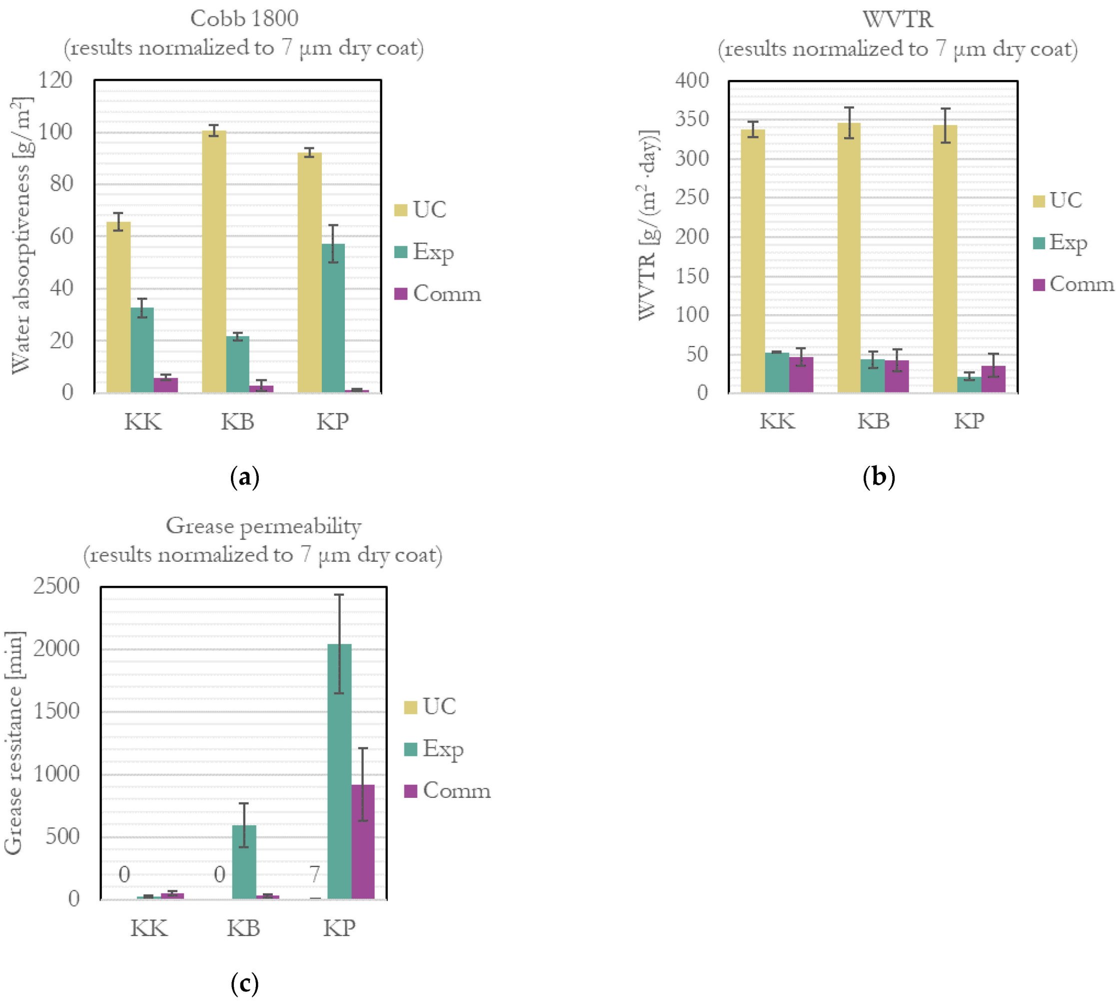


Figure 3. Measured barrier properties for both coated and uncoated substrates: (**a**) water absorption; (**b**) WVTR; (**c**) grease permeation. Some results are based on a previous study [14].

3.1.2. Roughness

The measured average R_zDIN is reported in Figure 4. A marked difference exists between different UC substrates. For KK and KB, the rougher substrates, the application of Exp or Comm seemed to slightly reduce overall UC surface roughness, though CD standard deviations are quite high and do not allow for statistical evidence. The effect was not highly marked due to low film grammages (hence, thicknesses). Compared to MD, CD roughness was higher for KK UC and KB UC, due to MD fiber alignment [39]. The same was not true for KP UC because of the double-coated layer. The latter substrate showed a slight roughness increase in CD when coated, possibly due to the conformation of the Meyer bar [14].

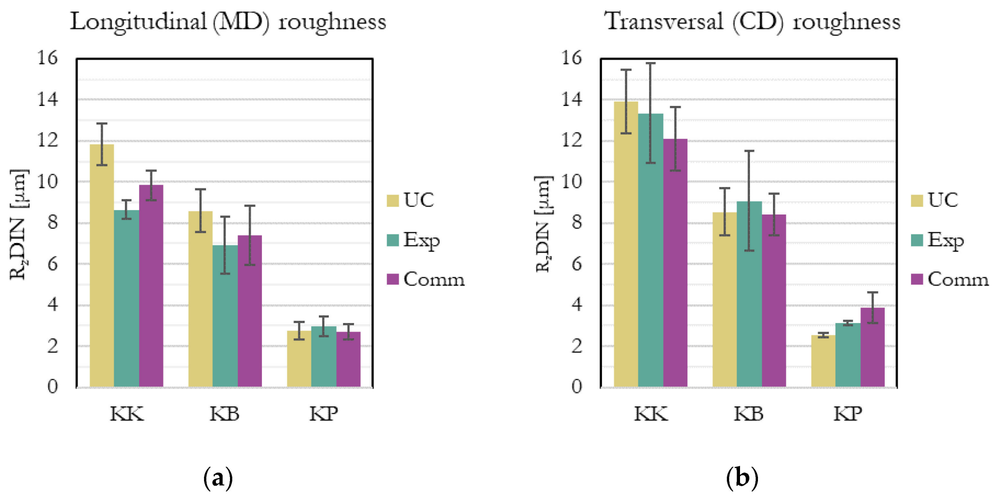


Figure 4. Measured roughness depending on substrate and coating: (**a**) alongside MD; (**b**) alongside CD.

3.1.3. Relative Gloss Value

Differently from what was observed for R_a, the diffused-illumination RGV strongly depended on the coating material (Figure 5). Two trends might be identified for the investigation matrix: (1) the RGV increases moving towards bleached and top-coated fibers; and (2) the coating material strongly affects the results, achieving increasing RGVs for Exp and Comm formulations. Additionally, the presence of mineral pigment inside the coating formulation was already reported to keep coat shininess to relatively low values [40]. In this case, Exp showed intermediate values compared to uncoated substrates and Comm formulation. Nevertheless, it should be considered how Comm and Exp have different polymeric latex natures, hence, possible different glosses. Indeed, to provide a reference value, neat experimental formulation latex applied on KB achieved 76 ± 3 RGV, i.e., even higher than Comm coating, further highlighting the crucial role of kaolin in reducing overall coat RGV.

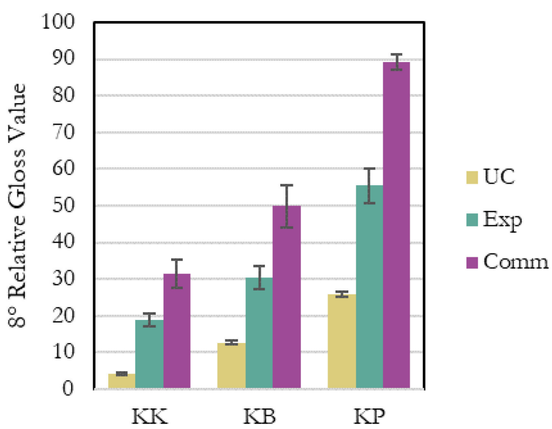


Figure 5. 8° relative gloss value for the coated and uncoated substrates.

3.1.4. Static Coefficient of Friction

The results (Figure 6) show how the experimental formulation achieved the highest static coefficient of friction for each substrate. This should be attributed to the intrinsic stickiness of the latex, which showed residual blocking traits in previous research [12]. It should be considered how, despite the overall higher stickiness within the investigated materials, kaolin should remodulate stickiness and blocking behavior [16]. Additionally, friction is a material-dependent property, hence the evaluation might provide different results when involving contact with, e.g., human skin. This, indeed, would have been the optimal choice given the aim of the research.

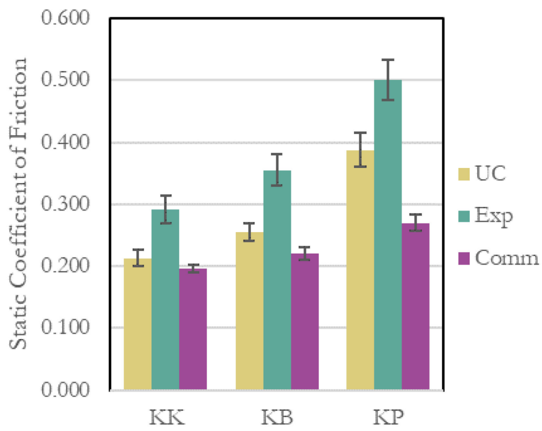


Figure 6. Coat-to-coat static coefficient of friction for the samples investigated.

3.2. Panel Test

3.2.1. Phases 1 and 2

The preliminary questionnaire about panelists' self-perception highlighted quite high values, showing median values of 7 and 8 for all the questions (Figure 7). The study involved users that state to care on average quite much about their role in correct sorting of packaging waste at home. However, there was an extreme variation concerning the reading of environmental labeling information. This means that the study involved both users who dispose of packaging waste trusting their perception and others who, regardless of their perception, trust what is reported on the label.

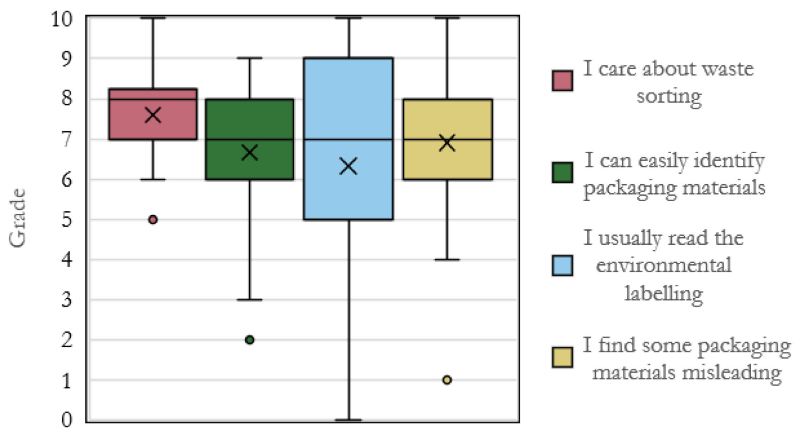


Figure 7. Panelists' self-perception about material recognition and sorting abilities.

Given the non-cellulosic content of the samples due to possible coating (around 7%, on average for coated specimens), all the samples were fiber-based materials and should therefore be thrown in the paper bin—this assumption is valid for this study, though recyclability tests according to diffused standards and methodologies [41,42] would provide further information about their effective recyclability.

Looking at the results (Figure 8) moving from kraft, rough, and uncoated (i.e., matte) surfaces towards white, smooth, and coated (i.e., shinier) surfaces, it is possible to observe how the perception of plastic and mixed waste increases, reducing the number of votes related to paper. A statistically significant ($p < 0.05$) strongly negative Pearson correlation (−0.837) was observed between sample sorting in the paper waste stream and measured RGV. Coat smoothness had a similar correlation, still achieving a slightly lower Pearson correlation value (−0.745).

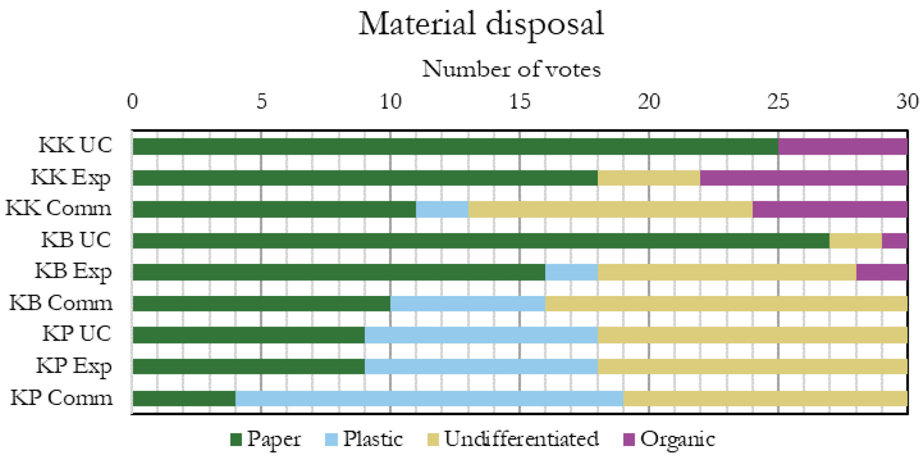


Figure 8. Panelists' votes breakup related to the disposal of each sample.

Additionally, KK substrate has a significant number of votes (≥5) related to organic/biomass. This might suggest panelists' association of brownish material with natural and compostable material, possibly related to previous experience related to compostable packaging, which is usually characterized by unbleached fibers.

As clearly visible in Figure 9, most of the participants (24 out of 30) overestimated themselves. On average, all the participants considered themselves 40% better than shown by real data—calculated as the ratio between the perceived over actual averages. This is somehow coherent with previous studies that highlight how, despite good attitudes, consumers might not always correctly sort all waste [28]. Nevertheless, it should be considered how all the samples contained at least ~90% cellulose, i.e., fiber based. In the present work, which differs from similar works related to the sorting of packaging waste, the authors investigated samples belonging to the very same waste collection stream, i.e., paper and board. Still, it seemed that even as low as 10% of non-cellulosic content strongly affected the consumers' perception, whose extent is discussed in this work.

A possible correlation between the actual and self-evaluation was assessed by calculating the Pearson correlation; despite a slightly positive correlation value (0.217), the relation was not statistically significant ($p > 0.05$).

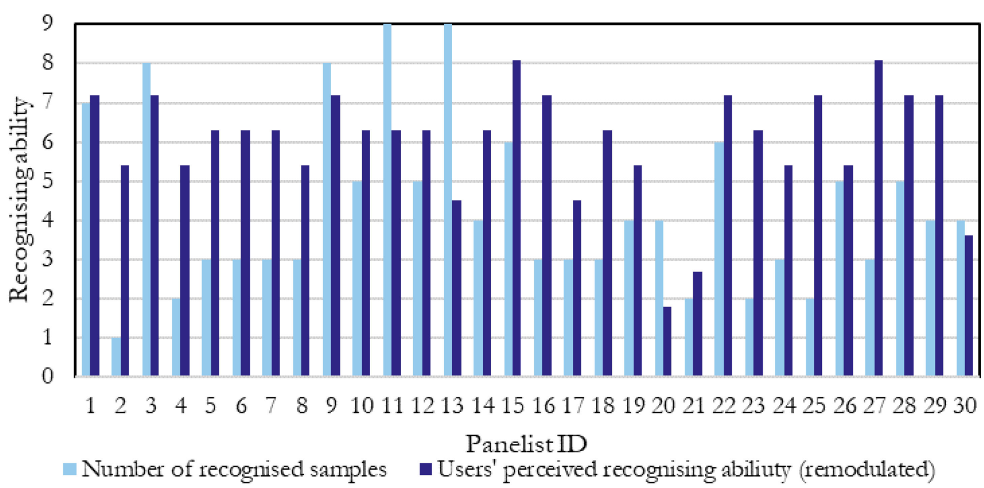


Figure 9. Panelists' self-recognizing ability perception compared to the number of correctly identified samples. Self-perception was remodulated from a 0−10 scale to a 0−9 scale.

3.2.2. Phase 3

It is visible from the mean values reported in Figure 10 how uncoated paper was perceived as more "paper-like", followed by the one coated with the experimental formulation and, finally, the one coated with the commercial formulation. Additionally, moving from KP to KK, there is a clear trend toward a "paper-like" perception. However, it should be underlined how, apart from KK UC and KP Comm, the interquartile range and whisker length were quite broad, and data was quite spread. Such behavior might be explained by a relatively small participant batch, as well as by the absence of a reference framework.

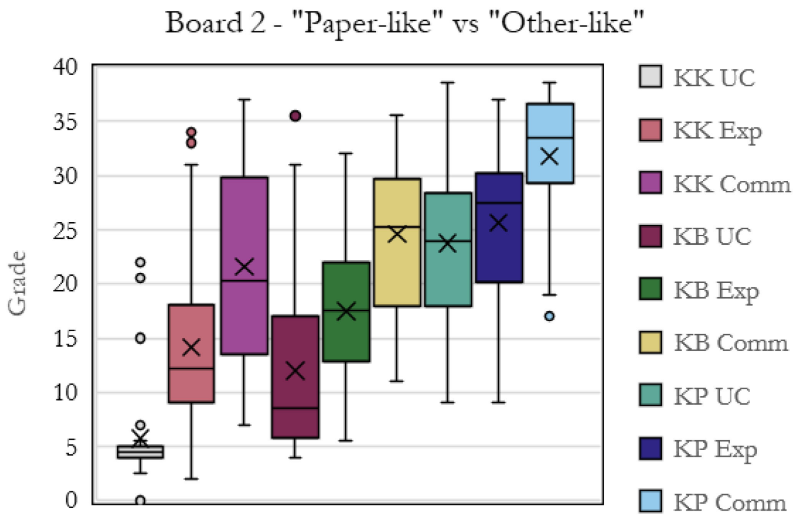


Figure 10. Results for the positioning of the samples along the "Paper-like" vs. "Other-like" axis. Values closer to 0 represent samples perceived as "Paper-like".

According to the provided answers, which are represented in Figure 11, specific attributes that helped participants discriminate different samples (i.e., >10 votes each) in this first evaluation were their glossiness, stickiness, smoothness, and presence of fibers.

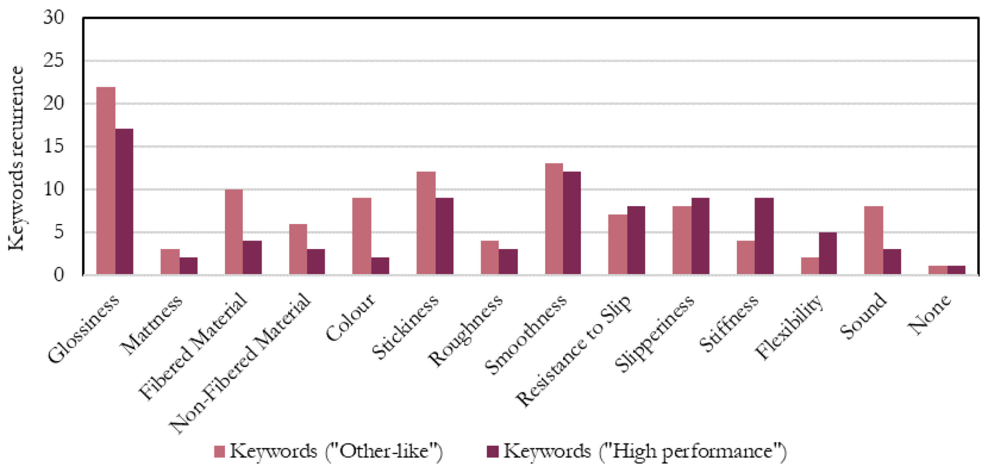


Figure 11. Keywords reported to have driven the choice in defining a material as "Other-like" and as characterized by "High performance".

Moving to perceived barrier performance, Figure 12 reports water barrier ones. The users perceived such barrier—as well as for moisture and grease—with the same considerations about the substrate and the coating as of Figure 10, related to "paper-like" versus "other-like" materials. This is coherent with general knowledge about fiber-based materials performance, which is limited if uncoated. However, although a strong (0.527) Pearson correlation, there was no statistical significance ($p > 0.05$) in the panelists' qualitative evaluation of the water barrier. Additionally, the samples were generally undervalued compared to the actual barrier.

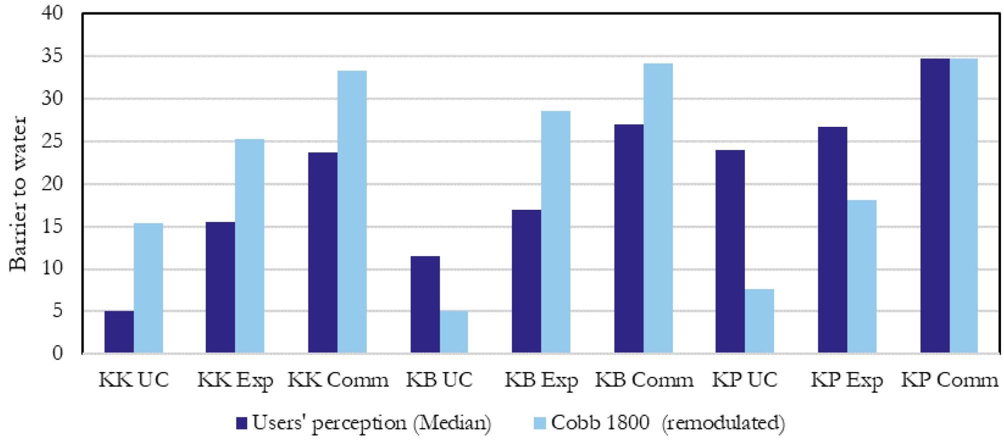


Figure 12. Water barrier performance. Panelists' perception (median value) versus actual remodulated water barrier (Cobb 1800). A higher barrier to water corresponds to lower Cobb 1800 values.

Considering the moisture barrier—and similar to water one—samples were usually undervalued (Figure 13). Nevertheless, users' perception achieved values that were close to the ones in Figure 12. The positive Pearson correlation (0.583) was not statistically significant ($p > 0.05$). It is interesting to highlight how, despite rougher and matter morphology, as well as similar WVTR, experimental coatings were considered to provide a worse moisture barrier compared to commercial dispersion-coated substrates.

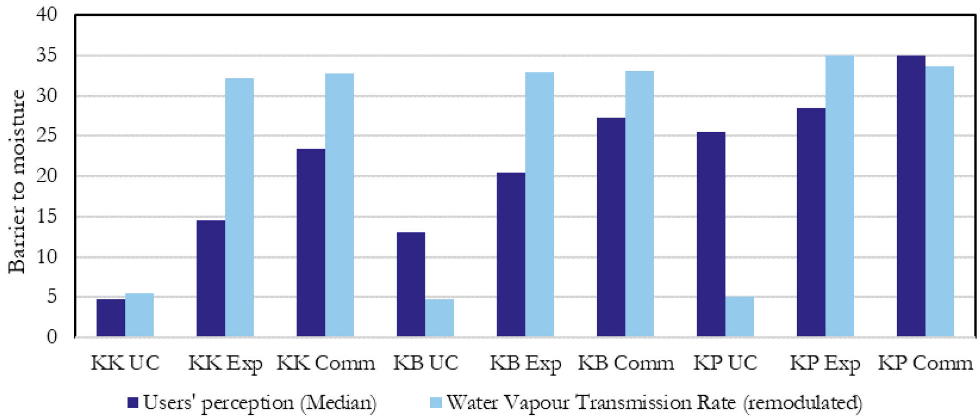


Figure 13. Moisture barrier performance. Panelists' perception (median value) versus actual remodulated moisture barrier (WVTR). A higher barrier to moisture corresponds to lower WVTR values.

Finally, the perceived grease barrier (Figure 14) seemed to be overvalued. However, this behavior is vitiated by the highest grease resistance shown by KP exp. Indeed, normalizing around 2000 min over a scale that is two orders of magnitude lower flattens any possible difference at low resistance values, as it was for most of the other samples.

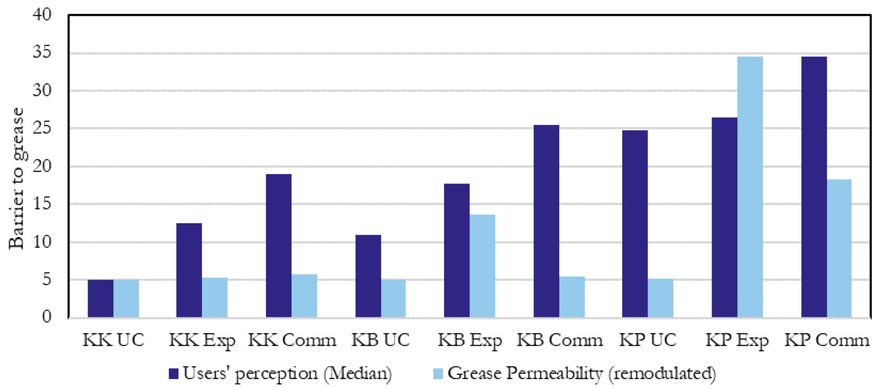


Figure 14. Grease barrier performance. Panelists' perception (median value) versus actual remodulated grease barrier.

Being panelists' evaluations close one each other for the three barrier properties—and despite broadly different barrier mechanisms—it can be pointed out how the aesthetic properties of both coated and uncoated samples do not provide any clue on the specific barrier property it can impart to the substrate. Nevertheless, visual and tactile properties did provide some information about possible protective layers that could improve barrier performance: it was the particular case of water and moisture barrier properties.

After the series of three unstructured scales, the most relevant keywords (>10 votes each) the panelists reported to have driven the choices about performance were glossiness and smoothness (Figure 11). Compared to the first round, it can be observed how most of the keywords saw a reduction in vote numbers, whereas it surged only for a few: slipperiness and resistance to slipping, stiffness, and flexibility. However, being two antonym couples, it would be expected an opposite trend between the two. Nevertheless, it is clear how the panelists preferred attributes associated with sight and sound for qualitative evaluation (i.e., where to dispose of waste); on the contrary, when associating attributes to quantitative concepts related to performance, attributes belonging to touch had a major impact.

3.2.3. Phase 4

Panelists proved to be able to determine and discriminate samples according to their smoothness and RGV. Unfortunately, it was not the case for slipperiness.

Regarding the smoothness (Figure 15), a strong, positive, and statistically significant Pearson correlation (0.933, $p < 0.05$) was observed. Users' perception seemed to be split across three main ranges, depending on the substrate: 5−10 for KK, 20−25 for KB, and around 30−35 for KP.

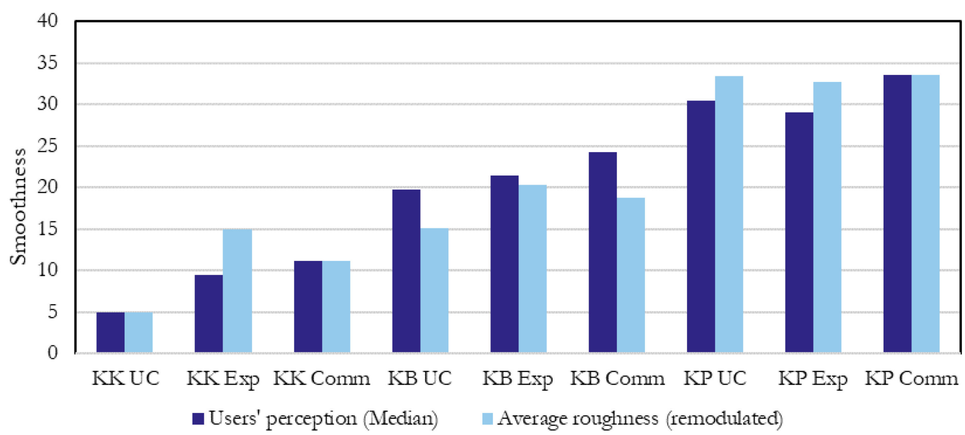


Figure 15. Smoothness. Panelists' perception (median value) versus actual remodulated roughness measurements. Higher smoothness corresponds to lower roughness values.

Similarly, the RGV (Figure 16) observed a strong, positive, and statistically significant Pearson correlation (0.874, $p < 0.05$). The panelists generally overestimated the shininess of the samples, still recognizing the most matte and glossiest samples. Moreover, it is clear how the users observed a clear trend among each substrate, with the experimental formulation achieving scores that were intermediate compared to uncoated and commercial dispersion-coated substrates.

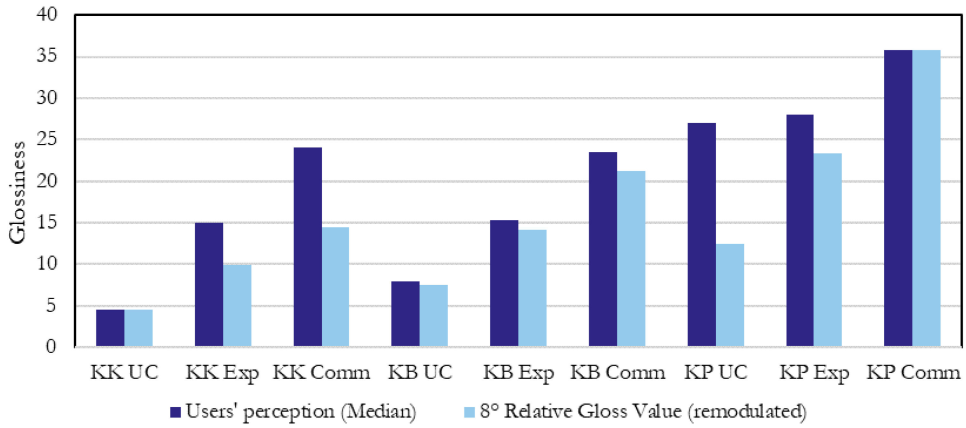


Figure 16. Glossiness. Panelists' perception (median value) versus remodulated 8° RGV measurements.

Slipperiness, whose results are reported in Figure 17, was the property that had sometimes controversial results from one panelist to another. This suggests that, despite the infographic (Figure A2), the concept might not be that clear, possibly requiring moderator intervention to better explain it. On the other hand, since panelists did not ask for further explanations, it might mean that they felt confident about their perception. Results show a slightly negative Pearson correlation (−0.416), which, however, is not statistically significant ($p > 0.05$).

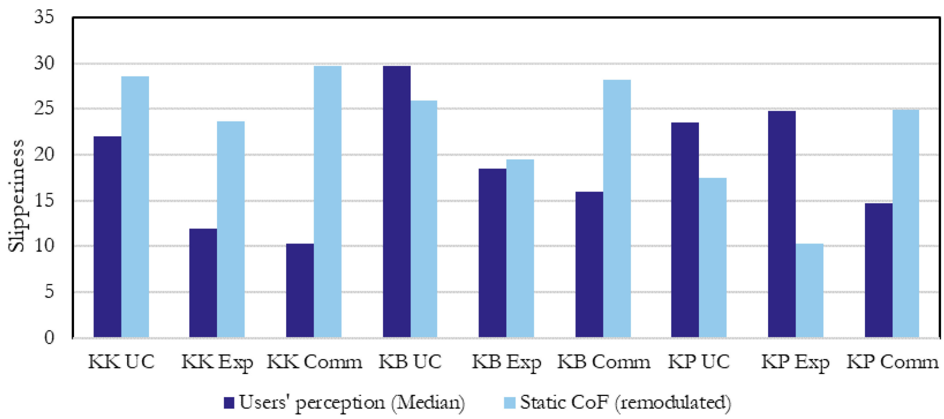


Figure 17. Slipperiness. Panelists' perception (median value) versus actual remodulated critical angle measurements. Higher slipperiness corresponds to lower critical angle values.

It is interesting to observe how panelists established a statistically significant correlation between sensorial properties (glossiness and smoothness) and perception of the sample as different from fiber-based substrates. Indeed, the results in Figure 10 are strongly and positively correlated to the ones in Figure 15 (0.828, $p < 0.05$) and Figure 16 (0.978, $p < 0.05$).

Coated/Uncoated sample perception is represented in Figure 18. Generally, users agreed on KK UC being uncoated, finding increasing difficulty in perceiving KB UC and KP UC as uncoated substrates, possibly due to its lower roughness and higher RGV (see Figures 4 and 5). Additionally, Comm-coated paper was usually identified as coated, whereas Exp generated more uncertainty in identifying coated samples.

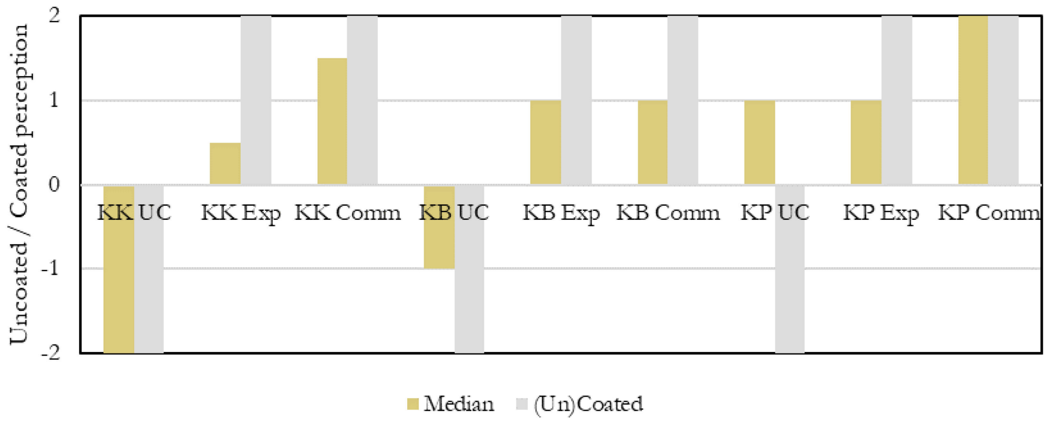


Figure 18. Panelists' opinion on whether each specimen was coated (+2) or not (−2).

4. Discussion

The results presented in this work, according to the author's knowledge, represent a singularity in the literature. Indeed, no previous study focused on paper packaging materials, simulating and assessing how barrier layers may affect consumer's material class identification, hence, waste sorting.

This work finds some limitations in the breadth of the outcomes due to a test group bounded essentially to the Italian context, and people in their twenties. Indeed, group age and geographical location are factors that were reported to affect the attitude toward household recycling [43,44]. Additionally, the panelist sample is surely not representative of an entire nation. Nevertheless, the present work highlighted interesting results that pose the basis for broader testing and future research, including, e.g., broader panelists' age range, actual packaging structures to be tested (moving from a decontextualized to a contextualized analysis [3]), or different (un)coated substrates of even higher grammage.

If, on the one hand, sensorial properties of the samples may provide misleading perceived barrier properties, on the other one, there was a clear and statistically significant positive correlation between aesthetic and morphologic properties. Untrained panelists proved to be strongly affected by aesthetic properties, especially when associated with packaging waste sorting. Correct sorting is, indeed, crucial to pursuing EU recycling targets [45], hence, the sustainability and circularity of the whole sector. Additionally, considering the limited time that consumers might dedicate to reading the environmental label and sorting waste, providing users a guiding perception might work as a "game-changer" towards improved material recyclability. Therefore, considering the results of the present study, rougher and matter surfaces help a paper-like perception that can help users recognize a sample as paper-based. Additionally, this study highlighted how even just 5−10% non-cellulosic content can negatively affect packaging perception, both on perceived performance and material recognition. Since previous research [15,46,47] reported how dispersion-coated fiber-based substrates might be easily recycled in paper mills, sample misinterpretation might prevent fibers from being recycled or, even worse, might pollute other recycling streams.

However, considering the packaging industry, a material perception design-led practice should not be aimed to confuse or cheat consumers. Indeed, letting them perceive a material to be different than what it is might mean, e.g., higher reject fractions at the recycling plant, hence, lowering recycling yields, reducing secondary raw material quality, or more frequent industrial plant shutdowns.

In this study, both mattness and roughness positively affected paper-like perception, hence, correct sorting. Additionally, Pearson correlation analysis showed how mattness/RGV seemed to be the leading parameter. This suggests how packaging producers as well as coating developers should carefully consider the overall implication of specific substrate and functional coating selection, given the fulfilment of the functional and regulatory constraints.

Not only that, a possible three-step process might take place for the consumers. At first, the material sample is studied, and its sensorial (i.e., visual, and tactile) characteristics are evaluated. Following that, the new experiential knowledge is associated with an already-existing knowledge, which is based on a set of case studies or material categories. Finally, the sorting action takes place, selecting the trash bin and pondering on the previous considerations. This statement might be supported by the perception of barrier properties (as of the "low performance" vs. "high performance" axis of Phase 3, see Figure 2b), where higher barrier properties are generally associated with samples not regarded as cellulosic (Figure 8). Indeed, the panelists associated good barrier properties with polymeric packaging. According to the authors, further exploration focused on a homogenized aesthetic design of paper-based packaging might improve correct disposal practices.

5. Conclusions

In this study, several paper substrates, either coated or uncoated, were provided to untrained panelists. The multi-phase panel test involved increasingly demanding cognitive effort to better focus on the aesthetic and perceptual properties of the samples. In their activity, panelists proved to be able to assess roughness and relative glossiness, achieving a highly positive correlation with characterization data. On the contrary, technical properties, e.g., barrier properties, were hardly perceived. Panelists strongly relied on sight and touch senses when identifying the constituent material of a sample. This research showed that it is possible to provide coated materials with improved barrier properties that suggest the "paper-like" perception to the consumer by acting on the coating formulation. Indeed, even thin coating layers whose content constitutes <10% of the total weight can play a crucial role in conveying correct experiential knowledge that impacts the effective material circularity.

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Appendix A

Following, the questions and possible answer pre-sets related to specific MS Forms activities are reported. Please note that more instructions (e.g., when to collect samples and change board) were reported on the boards themselves. Questions are divided according to the phase they were involved in.

Phase 1.

Instructions provided: the following questions try to better understand your attitude to packaging recycling. Make a grade of 0 to 10 depending on how well it reflects any of the following.

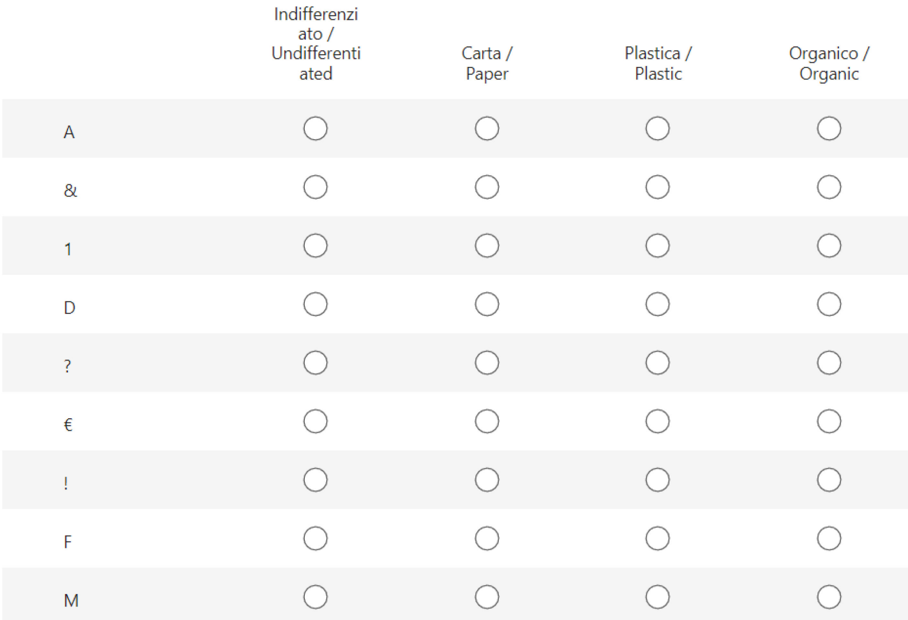
- I am a careful person to properly carry out the separate collection (0 = Completely disagree; 10 = totally agree)
- Looking at the packaging, I easily recognize in which recycle bin I should throw it (0 = Completely disagree; 10 = totally agree)

- When I have to dispose of the packaging, I read the environmental labeling (the environmental label states the bin where you should throw the packaging in) (0 = never; 10 = always)
- I ran into packaging that, given its sensorial property, I would have thrown in a different recycling stream compared to the one stated on the environmental label (0 = never; 10 = always)

Phase 2.

Instructions provided: move to board 1. You will be now given some material samples. You can interact as you prefer (please do not tear them up, we need them!). Follow the indications provided by the following questions.

- Place all the samples on board #1. In which recycling bin would you throw the materials? (When you finish to place the samples on the board, please report your choices in the following matrix)



	Indifferenziato / Undifferentiated	Carta / Paper	Plastica / Plastic	Organico / Organic
A	○	○	○	○
&	○	○	○	○
1	○	○	○	○
D	○	○	○	○
?	○	○	○	○
€	○	○	○	○
!	○	○	○	○
F	○	○	○	○
M	○	○	○	○

Figure A1. Matrix to be filled by the panelists. Each sample needed to be associated with a recycling stream.

Phase 3.

- In your opinion, which were the sensorial parameters that influenced your choices, making a sample perceived as non-cellulosic? (Multiple choice question)

○ Glossiness
○ Mattness
○ Fibered material
○ Non-fibered material
○ Color
○ Stickiness
○ Roughness
○ Smoothness
○ Resistance to slip
○ Slipperiness
○ Stiffness
○ Flexibility
○ Sound
○ None

- Other (Specify)

- In your opinion, which were the sensorial parameters that influenced your choices, making a sample perceived as of high performance? (Multiple choice question)
  - Glossiness
  - Mattness
  - Fibered material
  - Non-fibered material
  - Color
  - Stickiness
  - Roughness
  - Smoothness
  - Resistance to slip
  - Slipperiness
  - Stiffness
  - Flexibility
  - Sound
  - None
  - Other (Specify)

Phase 4.

Figure A2 reports the provided infographics to better explain the meaning difference of the attributes to be evaluated.

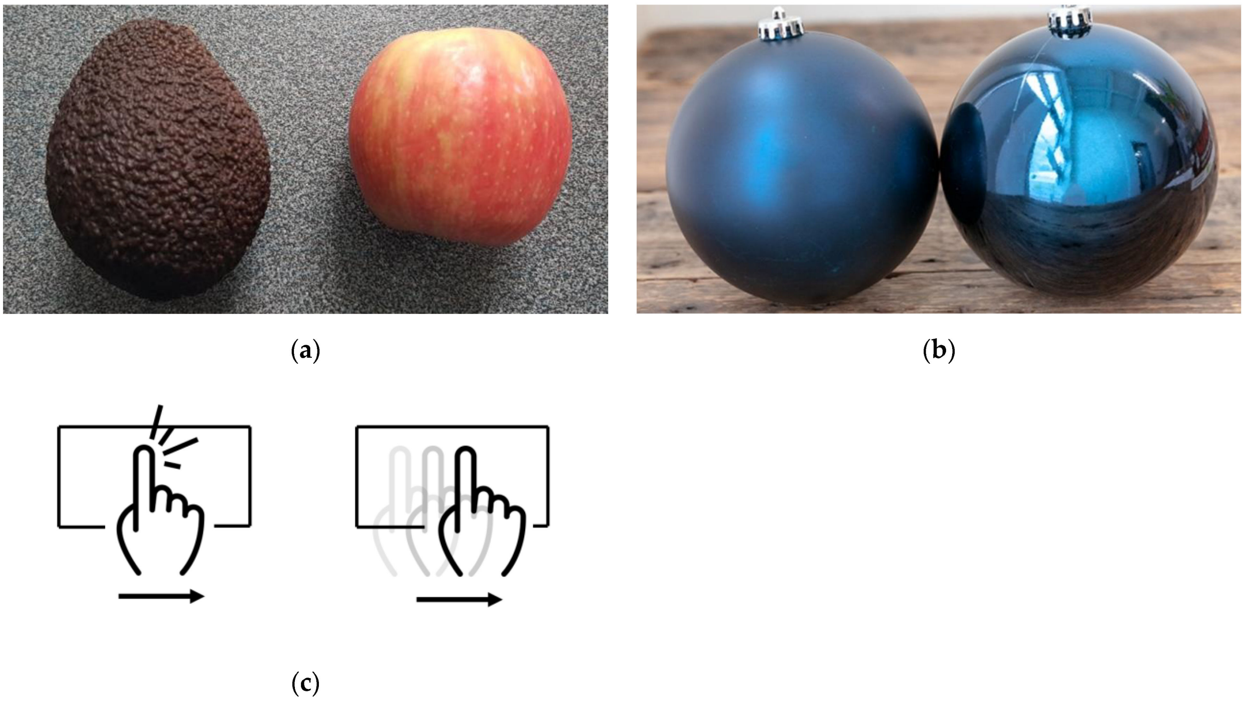


Figure A2. Provided infographics explaining the meaning of antonym descriptor couples: (**a**) Rough vs. Smooth; (**b**) Matte vs. Glossy; (**c**) Resistant to Slip vs. Slippery.

- According to your perception and for each sample, specify the chances it is coated with a functionalizing coating (to improve, e.g., water or grease barrier properties)

	−2 (Non rivestito / Uncoated)	−1	0	+1	+2 (Rivestito / Coated)
A	○	○	○	○	○
&	○	○	○	○	○
1	○	○	○	○	○
D	○	○	○	○	○
?	○	○	○	○	○
€	○	○	○	○	○
!	○	○	○	○	○
F	○	○	○	○	○
M	○	○	○	○	○

Figure A3. Matrix to be filled by the panelists. Each sample needed to be associated with the perceived probability that a sample was coated.

References

1. Ashby, M.F.; Johnson, K. *Materials and Design: The Art and Science of Material Selection in Product Design*, 3rd ed.; Butterworth-Heinemann: Oxford, UK, 2013; ISBN 0080982050.
2. Karana, E.; Hekkert, P.; Kandachar, P. Assessing Material Properties on Sensorial Scales. In Proceedings of the Volume 2: 29th Computers and Information in Engineering Conference, Parts A and B, ASMEDC, San Diego, CA, USA, 1 January 2009; pp. 911–916.
3. 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]
4. Karana, E.; Hekkert, P.; Kandachar, P. Meanings of Materials through Sensorial Properties and Manufacturing Processes. *Mater. Des.* **2009**, *30*, 2778–2784. [CrossRef]
5. Ljungberg, L.Y. Materials Selection and Design for Development of Sustainable Products. *Mater. Des.* **2007**, *28*, 466–479. [CrossRef]
6. Vezzoli, C. The "Material" Side of Design for Sustainability. In *Materials Experience*; Elsevier: Amsterdam, The Netherlands, 2014; pp. 105–121.
7. Mielinger, E.; Weinrich, R. A Review on Consumer Sorting Behaviour: Spotlight on Food and Fast Moving Consumer Goods Plastic Packaging. *Environ. Dev.* **2023**, *47*, 100890. [CrossRef]
8. Hidalgo-Carvajal, D.; Gutierrez-Franco, E.; Mejia-Argueta, C.; Suntura-Escobar, H. Out of the Box: Exploring Cardboard Returnability in Nanostore Supply Chains. *Sustainability* **2023**, *15*, 7804. [CrossRef]
9. García-Arca, J.; Comesaña-Benavides, J.A.; González-Portela Garrido, A.T.; Prado-Prado, J.C. Rethinking the Box for Sustainable Logistics. *Sustainability* **2020**, *12*, 1870. [CrossRef]
10. Eurostat Packaging Waste Statistics. 2020. Available online: https://ec.europa.eu/eurostat/statisticsexplained/ (accessed on 1 April 2020).
11. European Parliament Directive (EU) 2019/904. 2019. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32019L0904 (accessed on 12 April 2019).
12. Marinelli, A.; Profaizer, M.; Diamanti, M.V.; Pedeferri, M.; Del Curto, B. Heat-Seal Ability and Fold Cracking Resistance of Kaolin-Filled Styrene-Butadiene-Based Aqueous Dispersions for Paper-Based Packaging. *Coatings* **2023**, *13*, 975. [CrossRef]
13. Merabtene, M.; Tanninen, P.; Wolf, J.; Kayatz, F.; Hauptmann, M.; Saukkonen, E.; Pesonen, A.; Laukala, T.; Varis, J.; Leminen, V. Heat-Sealing and Microscopic Evaluation of Paper-Based Coated Materials Using Various Seal Bar Geometries in Vertical Form Fill Seal Machine. *Packag. Technol. Sci.* **2023**, *36*, 667–679. [CrossRef]
14. Marinelli, A.; Diamanti, M.V.; Pedeferri, M.P.; Del Curto, B. Kaolin-Filled Styrene-Butadiene-Based Dispersion Coatings for Paper-Based Packaging: Effect on Water, Moisture, and Grease Barrier Properties. *Coatings* **2023**, *13*, 195. [CrossRef]
15. Bakker, S.; Kloos, J.; Metselaar, G.A.; Catarina, A.; Esteves, C.; Schenning, A.P.H.J. About Gas Barrier Performance and Recyclability of Waterborne Coatings on Paperboard. *Coatings* **2022**, *12*, 1841. [CrossRef]
16. Bollström, R.; Nyqvist, R.; Preston, J.; Salminen, P.; Toivakka, M. Barrier Properties Created by Dispersion Coating. *TAPPI J.* **2013**, *12*, 45–51. [CrossRef]
17. CPI Paper and Board Packaging. Design for Recyclability Guidelines. 2022. Available online: https://thecpi.org.uk/library/PDF/Public/Publications/Guidance%20Documents/CPI_guidelines_2022-WEB.pdf (accessed on 3 October 2022).
18. Cepi Paper-Based Packaging Recyclability Guidelines. Available online: https://www.cepi.org/wp-content/uploads/2020/10/Cepi_recyclability-guidelines.pdf (accessed on 15 July 2020).

19. CONAI Linee Guida per La Facilitazione Delle Attività Di Riciclo Degli Imballaggi a Prevalenza Cellulosica. Available online: http://www.progettarericiclo.com/docs/linee-guida-la-facilitazione-delle-attivita-di-riciclo-degli-imballaggi-prevalenza-cellulosica (accessed on 4 September 2020).
20. CITEO Règles de Recyclabilité. 2019. Available online: http://unblogsurlaterre.com/wp-content/uploads/2019/03/Regles_de_recyclabilite_TREE.pdf (accessed on 15 July 2019).
21. Rousta, K.; Dahlén, L. Source Separation of Household Waste: Technology and Social Aspects. In *Resource Recovery to Approach Zero Municipal Waste*; Taherzadeh, M., Richards, T., Eds.; CRC Press: Boca Raton, FL, USA, 2015; pp. 61–76. ISBN 9781482240351.
22. Henriksson, G.; Åkesson, L.; Ewert, S. Uncertainty Regarding Waste Handling in Everyday Life. *Sustainability* **2010**, *2*, 2799–2813. [CrossRef]
23. Ajzen, I. The Theory of Planned Behavior. *Organ. Behav. Hum. Decis. Process.* **1991**, *50*, 179–211. [CrossRef]
24. Wojciechowska, P.; Wiszumirska, K. Sustainable Communication in the B2C Market—The Impact of Packaging. *Sustainability* **2022**, *14*, 2824. [CrossRef]
25. Nemat, B.; Razzaghi, M.; Bolton, K.; Rousta, K. The Potential of Food Packaging Attributes to Influence Consumers' Decisions to Sort Waste. *Sustainability* **2020**, *12*, 2234. [CrossRef]
26. Fishbein, M.; Ajzen, I. *Belief, Attitude, Intention and Behaviour: An Introduction to Theory and Research*; Addison-Wesley Publishing Co: Boston, MA, USA, 1975.
27. D'souza, C.; Taghian, M.; Lamb, P.; Peretiatko, R. Green Decisions: Demographics and Consumer Understanding of Environmental Labels. *Int. J. Consum. Stud.* **2007**, *31*, 371–376. [CrossRef]
28. Langley, J.; Turner, N.; Yoxall, A. Attributes of Packaging and Influences on Waste. *Packag. Technol. Sci.* **2011**, *24*, 161–175. [CrossRef]
29. Wikström, F.; Williams, H.; Verghese, K.; Clune, S. The Influence of Packaging Attributes on Consumer Behaviour in Food-Packaging Life Cycle Assessment Studies—A Neglected Topic. *J. Clean. Prod.* **2014**, *73*, 100–108. [CrossRef]
30. Nemat, B.; Razzaghi, M.; Bolton, K.; Rousta, K. The Role of Food Packaging Design in Consumer Recycling Behavior—A Literature Review. *Sustainability* **2019**, *11*, 4350. [CrossRef]
31. Boz, Z.; Korhonen, V.; Koelsch Sand, C. Consumer Considerations for the Implementation of Sustainable Packaging: A Review. *Sustainability* **2020**, *12*, 2192. [CrossRef]
32. Steenis, N.D.; van Herpen, E.; van der Lans, I.A.; Ligthart, T.N.; van Trijp, H.C.M. Consumer Response to Packaging Design: The Role of Packaging Materials and Graphics in Sustainability Perceptions and Product Evaluations. *J. Clean. Prod.* **2017**, *162*, 286–298. [CrossRef]
33. Marinelli, A.; Papile, F.; Del Curto, B. Design for Recycling Guidelines of Paper-Based Packaging—A Review for Packaging Designers. In Proceedings of the 3rd International Circular Packaging Conference, Ljubljana, Slovenia, 19–20 October 2023; Kavčič, U., Lavrič, G., Eds.; Pulp and Paper Institute: Ljubljana, Slovenia; Faculty of Polymer Technology: Ljubljana, Slovenia, 2023.
34. *BS EN ISO 535:2014*; Paper and Board. Determination of Water Absorptiveness. Cobb Method. ISO: Geneva, Switzerland, 2014. Available online: https://bsol.bsigroup.com/Bibliographic/BibliographicInfoData/000000000030259603 (accessed on 5 January 2021).
35. *BS ISO 2528:2017*; Sheet Materials. Determination of Water Vapour Transmission Rate (WVTR). Gravimetric (Dish) Method. ISO: Geneva, Switzerland, 2017. Available online: https://bsol.bsigroup.com/Bibliographic/BibliographicInfoData/000000000030349864 (accessed on 3 March 2022).
36. *BS ISO 16532-1:2008*; Paper and Board. Determination of Grease Resistance. Permeability Test. ISO: Geneva, Switzerland, 2008. Available online: https://bsol.bsigroup.com/Bibliographic/BibliographicInfoData/000000000030164327 (accessed on 2 February 2022).
37. *ASTM D4918-97:2007*; Standard Test Method for Coefficient of Static Friction of Uncoated Writing and Printing Paper by Use of the Inclined Plane Method. ASTM International: West Conshohocken, PA, USA, 2007.
38. Piselli, A.; Baxter, W.; Simonato, M.; Del Curto, B.; Aurisicchio, M. Development and Evaluation of a Methodology to Integrate Technical and Sensorial Properties in Materials Selection. *Mater. Des.* **2018**, *153*, 259–272. [CrossRef]
39. Alam, A.; Thim, J.; Manuilskiy, A.; O'nils, M.; Westerlind, C.; Lindgren, J.; Lidén, J. Investigation of the Surface Topographical Differences between the Cross Direction and the Machine Direction for Newspaper and Paperboard. *Nord. Pulp Pap. Res. J.* **2011**, *26*, 468–475. [CrossRef]
40. Schuman, T.; Karlsson, A.; Larsson, J.; Wikström, M.; Rigdahl, M. Characteristics of Pigment-Filled Polymer Coatings on Paperboard. *Prog. Org. Coat.* **2005**, *54*, 360–371. [CrossRef]
41. UNI UNI 11743:2019. Available online: http://store.uni.com/catalogo/uni-11743-2019?josso_back_to=http://store.uni.com/josso-security-check.php&josso_cmd=login_optional&josso_partnerapp_host=store.uni.com (accessed on 2 July 2019).
42. Cepi Harmonised European Laboratory Test Method to Generate Parameters Enabling the Assessment of the Recyclability of Paper and Board Products in Standard Paper and Board Recycling Mills. 2022. Available online: https://www.cepi.org/cepi-recyclability-test-method-version-2/ (accessed on 20 October 2022).
43. Rousta, K.; Bolton, K.; Dahlén, L. A Procedure to Transform Recycling Behavior for Source Separation of Household Waste. *Recycling* **2016**, *1*, 147–165. [CrossRef]

44. Zhang, H.; Wen, Z.-G. Residents' Household Solid Waste (HSW) Source Separation Activity: A Case Study of Suzhou, China. *Sustainability* **2014**, *6*, 6446–6466. [CrossRef]
45. European Parliament and Council Directive (EU) 2018/852. Available online: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32018L0852 (accessed on 10 February 2019).
46. Andersson, C. New Ways to Enhance the Functionality of Paperboard by Surface Treatment—A Review. *Packag. Technol. Sci.* **2008**, *21*, 339–373. [CrossRef]
47. Zhu, Y.; Bousfield, D.; Gramlich, W.M. The Influence of Pigment Type and Loading on Water Vapor Barrier Properties of Paper Coatings before and after Folding. *Prog. Org. Coat.* **2019**, *132*, 201–210. [CrossRef]