Design from Recycling

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Abstract

The amount of materials that industrial design engineers can choose from to materialise their designs keeps increasing. However, emerging new materials such as recycled plastics often struggle to get adopted after their introduction to the competitive market. This paper elaborates on the first steps within an interdisciplinary research project between materials science and industrial design engineering regarding ‘Design from Recycling’ (DfromR) that aims to design specifically with both post-consumer and post-industrial mixed recycled plastics that are industrially processed through extrusion or injection moulding. The goal of this research paper is to search for a practical and methodological support for designing with the recycled plastic waste streams, which can be applied to the upcoming cases in the Design from Recycling project. Due to similarities with this ongoing research, the existing Material Driven Design (MDD) method is chosen as a reference method. However, to address the expected challenges regarding the specific context of industrial processing techniques, we propose and present two additional steps: (i) an elaborated technical characterisation in the engineering lab, leading to a virgin-recycled comparison table concerning the main technical material properties that need to be translated to designerly descriptions, and (ii) an user-centred consumer evaluation of the experiential material characteristics of the provided shape-independent samples, leading to experiential moodboards. To conclude, the paper presents the interpretation of the four steps in the MDD process in the context of the material cases of the ongoing Design from Recycling project.

Keywords

Design from Recycling; Mixed recycled plastics; Material Driven Design; Industrial design engineering; Materials experience

Materials as such have been extensively studied in science and engineering for years. As part of the growing product consumption and rapid technological development, increasingly more new materials emerge and are commercialised (Forester, 1988). This implies that, more and more of the traditional engineering materials are substituted by these ‘new materials’ (Rao, 2008) (e.g., bio-based materials, smart materials, recycled and/or recyclable materials). Hence, the available set of materials is rapidly growing both in type and number (Roth, Field, & Clark, 1994). Researchers estimated that there were over 80,000 technical materials in the world in 2010 (Jahan, Ismail, Sapuan, & Mustapha, 2010). Consequently, the amount of materials that industrial design engineers can choose from to materialise their designs, keeps increasing (Hasling, 2016). Since it no longer suffices to count on design experience with familiar materials, the selection and use of appropriate materials for a design becomes a lengthy, time-consuming and expensive process (Karana, Hekkert, & Kandachar, 2008a). Notwithstanding the fact that new materials gain more attention by designers in the past decade (Karana, Pedgley, Rognoli, & Korsunsky, 2016; Rognoli, Bianchini, Maffei, & Karana, 2015), often they still struggle to get adopted after their introduction to the competitive market (Maine, Probert, & Ashby, 2005). However, this evolution is insurmountable in the context of the current scarcity of raw materials, leading designers to (re)consider the entire lifecycle of their products to facilitate a circular and sustainable economy.

Context

This research paper is a part of the ongoing project “Design from Recycling”, an interdisciplinary collaboration between the University of Antwerp (Product Development) and the University of Ghent (Applied Materials Science). The purpose of this technology transfer (TETRA) project is to provide Flemish SMEs with the necessary knowledge and support to design and manufacture more and better products from recycled plastics, which should be considered as new high potential materials.

Design for Recycling is a fairly well-known strategy, where one focuses during the design process on the recyclability of products at their end of life. By contrast, **Design from Recycling** (DfromR) is a new approach within the concept of circular economy, which examines to what extent a new product can be produced from an existing flow of recycled polymers, and the design specifications this entails (Ragaert, 2016). Consequently, this project wants to provide an answer to the research question: “How do we design specifically with recycled plastics?”. The challenge lies not in the application of these recyclates in low-grade applications, but rather in high quality, sustainable products.

To date, material engineers are able to recycle and industrially process mixed plastic waste (Ragaert, 2015). Within this research project, the plastic waste is mechanically recycled, resulting in small flakes or pellets (Ragaert, 2016). Different groups of waste materials can be distinguished: either post-industrial or post-consumer, and varying between a single unpolluted polymer versus multiple, contaminated polymers (Hubo & Ragaert, 2014). The Design from Recycling project focuses on the industrial manufacturing techniques of extrusion and injection moulding, leading to the design and manufacturing of high quality consumer goods.

However, most stakeholders expressed (e.g. engineers, suppliers, manufacturers and designers) experiencing an impasse at the point of implementing these new materials in designs. By habit, they frequently try to simply substitute and mimic traditional materials in existing products, without considering the consequences, or without taking advantage of their unique identity and meaningful opportunities. Therefore, they often fail when introduced to the market as they are not socially and culturally accepted (Karana, Barati, Rognoli, & Zeeuw van der Laan, 2015; Manzini, 1986).

So, how can we differentiate recycled plastics on the market and towards consumers? Especially when the application of industrial processes such as extrusion and injection moulding reduces the recycled appearance and attitude of those materials. Should we emphasize this, or not at all? How can industrial design engineers influence the materials experience, i.e. “the experiences that people have with, and through, the materials of a product” (Karana et al., 2015; Karana, Hekkert, & Kandachar, 2008b)? This raises the question: how should we design with these mixed recycled plastic materials specifically?

Aim of the research

To facilitate the specific design process that has a mixed recycled plastic waste stream as the main starting point, we need a systematic guidance to support industrial design engineers (IDE) in this process. Accordingly, the goal of this research is to explore and define a practical and methodological support for designing with recycled plastics, that can be directly applied to the cases of the Design from Recycling project. In order to construct this set-up, three research questions were addressed in the following sections:

- What are the existing design approaches that could be applied to the cases of the Design from Recycling project? And consequently, which approach is most useful?
- What difficulties or limitations of the choses approach are expected during application? What adaptations might be needed to set-up this specific cases?
- How can the chosen approach be interpreted in the Design from Recycling cases?

Review on existing approaches

There is already a large body of research in the field of mechanical engineering, examining the material selection process from the viewpoint of materials science and engineering (Ashby, 2011). Only recently, attention shifted to the user-centred perspective of experiential characteristics and user-interaction (Hasling, 2016; Karana, 2009; Van Kesteren, 2008). To summarise, the different aspects of materials can be for the most part categorised in two groups, namely the engineering aspects and the experiential aspects (Hasling, 2016; Van Kesteren, Stappers, & de Bruijn, 2007). The technical aspects of materials define how the product will be manufactured and how it will function, whereas the experiential aspects are those that influence the usability, sensory appeal, experience, and personality of a product. (Giaccardi & Karana, 2015; Hasling, 2016). Obviously, to include all material considerations in a design process, also economic and ecological aspects have to be taken into account. However, the criticality lies precisely in the multidisciplinary combination of several material aspects and their interrelations. Hence, four main material considerations can be defined: technical properties, experiential characteristics, economic aspects, and ecological aspects. For the sake of completeness, social sustainability is currently not considered within material characterisation.

There is an extensive amount of tools or approaches from an engineering perspective, see Jahan et al. (2010) and previous research (Veelaert, Du Bois, Ragaert, Hubo, & Van Kets, 2016), but the Cambridge Engineering Selector (CES) Software of Granta Design (Granta, 2016) is probably the best-known. Their recent ‘Products, Materials and Processes’ database tries to bridge the gap between engineers and designers and is therefore included in this enumeration. However, it does not really provide a structured design approach to design with mixed recycled plastics as a starting point. Nevertheless, it can be useful to explore and visualise the technical properties in relation to other well-known and common materials.

From the IDE perspective, the following tools were selected. Van Kesteren et al. (2007) proposed the *Materials in Product Selection* (MiPS) tools consisting of a Picture, Sample, Question and Relation Tool to facilitate the materials selection process in terms of user-interaction and sensorial attributes. The *Expressive-Sensorial Atlas* by Rognoli (2004; 2010) focuses on experiential learning of material properties (Karana, Pedgley, & Rognoli, 2013) and wants to show the relation between sensorial attributes and a material’s perception by people. Karana et al. (2010; Karana, 2009) constructed the *Meanings of Materials* (MoM) model that explores the effect of expressive material characteristics on the meanings it will convey. Building on these foundations, Karana et al. (2015) introduced the *Material Driven Design* (MDD) method that structures a design process with a specific (new) material as the starting point, while bridging both the technical and the experiential perspective during four key activities.

Conclusions

In order to build upon existing knowledge and tools, the Material Driven Design (MDD) method was chosen as reference method due to its similarities with the Design from Recycling project that also puts a particular material – a mixed recycled plastic – as the basis for the design process. In addition, this approach also includes other existing tools - such as the MoM model - throughout its process.

However, according to our understanding, the challenge lies in the limitations of the industrial processing techniques (i.e. extrusion and injection moulding) that are used in our specific research project, which complicates manual tinkering with materials to explore them, as is currently done in the MDD cases with for example coffee waste (Karana et al., 2015) or mycelium-based composites (Parisi, Garcia, & Rognoli, 2016). Consequently, we propose two novelties to extend the current MDD method. First, we feel the need to further **elaborate on the technical characterisation** step (i) of this method and rework it to the context of our recycled materials and the more industrial environment and processing techniques. As a consequence of this industrial processing, the available material samples do not have a typical ecological or recycled appearance. Therefore, we want to accentuate the **end-user (consumer) evaluation** of the experiential characteristics of the materials exploration already in the beginning of the MDD process step (ii). In the following Section these additional steps will be explained.

Additional steps on a technical level

Relevant and critical materials considerations

Continuing on the elaborated technical characterisation possibilities from an engineering point of view, we need to know what to measure within this specific project context of Design from Recycling, in order to ultimately develop a comparison approach for recycled versus virgin plastics. To date, only limited knowledge is available on our new recycled plastic materials. In contrast to virgin materials, these mixed recycled plastics can derive from either post-industrial or post-consumer waste.

The initial research activity in this project addresses the search for a condensed list of the most relevant and critical material properties for all project partners (e.g. material engineers, industrial design engineers, processors and mould makers). Here, the goal is to identify the collection of materials data that is minimally required and that needs to be communicated between the stakeholders.

A first proposal was compiled during several conversations between experts from both material science and industrial design engineering (IDE) perspective, and then introduced to the members of the project's user committee. A reasoning with consequences approach was used to start identifying the differences between 'ability to measure' and 'need to measure'. The material scientists clarified what characteristics they usually measure, what standards they are used to fill in datasheets, and what their limitations are for measuring certain material characteristics, however focusing on properties that are needed for the injection moulding process. From the industrial design engineering perspective, a first reasoning was done explaining the specific characteristics they need to make design decisions and to select materials in the different phases of the design process. Matching these two perspectives is important to (i) eliminate unnecessary measurements (at the engineering lab), (ii) avoid missing information (that could lead to a non-use in the design practice), and (iii) build a common understanding to facilitate discussion and knowledge transfer. The concluding proposal is visualised in Figure 1.

technical				economic	ecological
mechanical	tensile strength	chemical	permeability	price	environemental impact
	flexural strength		water absorption	availability	recyclable?
	E-modulus		chemical resistance		biodegradable?
	flexural modulus		UV resistance		renewable source?
	yield point	thermal	service temperature (no load)		
	elongation (%) at break		service temperature (load)		
	creep resistance		thermal conductivity		
	notched impact strength		thermal expansion		
	hardness		glass temperature		
	fracture toughness	processing	viscosity		
physical	density		mold shrinkage		
			processing techniques		

Fig 1. First proposal of technical, economic, ecological material properties within DfromR project.

Survey with IDE: method, participants, and results

The next step was to verify this list of chosen material characteristics with IDE in the field. Therefore, an online survey was conducted on the relevance and criticality of each of the material properties and characteristics over the three domains that are mentioned above (excluding experiential characteristics). For each material consideration category, respondents were asked whether a listed material property or characteristic was critical for them to know (for materials selection) throughout an average design process with plastics. Focus was not yet put on recycled plastics specifically since we argue that these materials should be presented and incorporated in the same and thus comparable manner as materials information on regular and well-known plastics, in order to facilitate the adoption of recyclates in the usual materials selection process. To rate the relevance of each property, respondents could choose between “yes”, “sometimes”, “no”, or “unfamiliar with the listed property”. At the end, respondents were free to add any properties that they missed in the list.

Through the alumni network of Product Development Department, fifty four respondents from design agencies, R&D departments and academia completed the online survey. The results were transferred to a datasheet and processed as listed below in Figure 2.

Fig 2. Results of the survey regarding the relevance of the proposed material properties.

To decide whether or not a material property could be omitted from the datasheet - from an industrial design engineering perspective - a critical threshold was set at both 50 percent and 80 percent. Consequently, all the material characteristics within 50 percent (“yes” and “sometimes” answers combined) are absolutely critical and are to be part of this project’s datasheet. To accommodate the broader information needs, only the material characteristics above 80 percent will be left behind in the continuation.

These results lead to the conclusion that the proposed data table is quite accurate, but that it is justified to omit the following material characteristics from the IDE’s viewpoint: elongation (%) at break, flexural modulus, glass temperature, and biodegradability. Consequently, this leaves us with a compact data table with the minimally required (relevant) material information that is necessary to proceed with the next project step: to design with these recycled plastics. As can be expected from IDE, especially the possible processing techniques, the price and availability of materials are an absolute must-know in the design process.

Extended technical research step

To conclude, the list of relevant material characteristics can be edited to a final version. At this point, the technical part of the table can be addressed. In order to practically use the obtained datasheet in the MDD method, this extended technical research step consists of three parts:

- Identification of missing material information that still needs to be measure, in contrast to information that can be reasoned ‘as virgin’ (A);
- Actual measurement of the technical data at the engineering lab according to standards (B);
- Interpretation and translation of the technical data into designerly descriptions (C).

A. Reasoning ‘as virgin’ - what to measure

Based upon the table of the desired technical material properties, further reasoning with consequences was done related to the technical characteristics. Material experts within the project were asked to - based on information of a previous research project about recycled mono polyolefins (Hubo & Ragaert, 2014) - make a comparison between virgin plastics and recycled plastics. During this focus group discussion, they had to indicate the manner of how each technical property of recycled plastics would differentiate from its virgin material (Figure 3). If, according to their experience, there was no relation between the virgin and the recycled plastic, the property should definitely be measured (third bullet coloured). However, ‘not equal’ does not necessarily indicate that the recycled property is worse, f.e. in the case of price and environmental impact. On the other hand, for those characteristics whose first bullet is coloured, a relationship could be determined (’as virgin’). For some characteristics, there was no doubt that the recyclates would act similar as the virgins, for others this only applies to post-industrial recyclates (second bullet coloured). This difference is due to the fact that post-consumer recyclates often had a long lifetime and their characteristics have changed due to UV radiation and pollution or contamination of other substances. However, these are global guidelines; the third bullet does not mean that the property can never be equal, but you cannot assume it is.

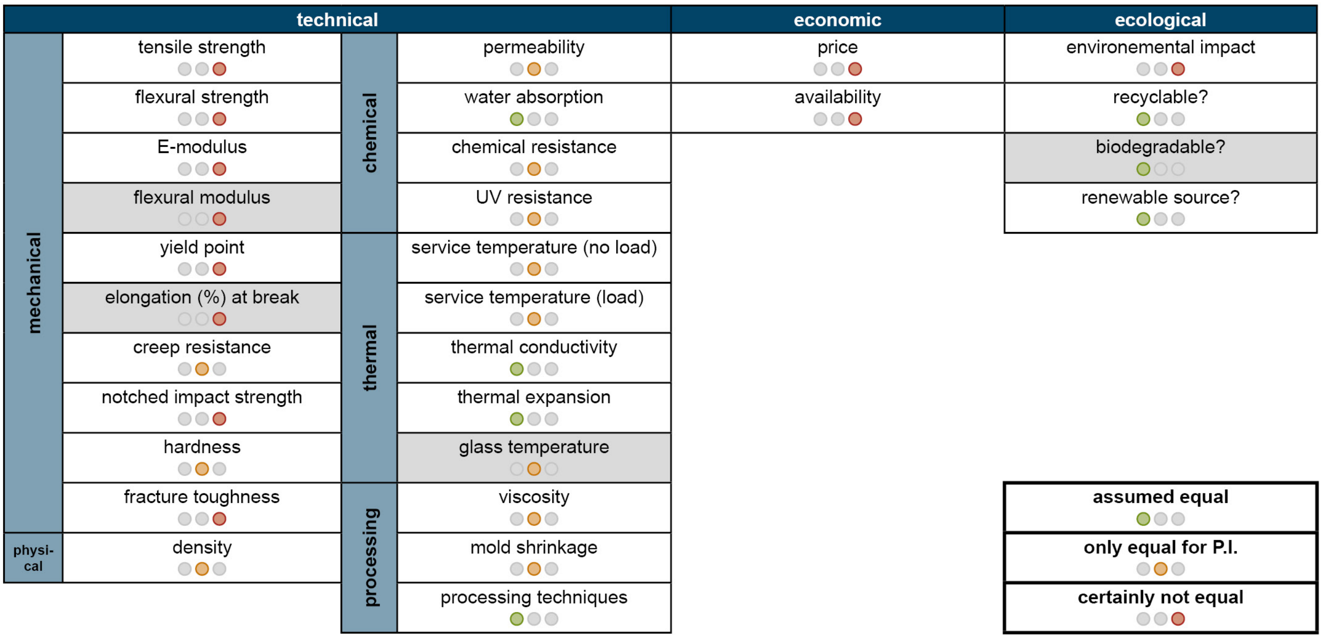

Fig 3. Table of technical, economic and ecological properties including the comparison of recycled plastics with virgins.

B. Measurement of the technical data according to standards

Once the missing technical information is identified – i.e. the information that cannot be assumed similar to the corresponding virgin plastics – standardised tests can be carried out in the engineering lab by means of test bars, both dog-bone and rectangular shaped, as visualised in Figure 4.

Fig 4. Test bars used for standardised testing, made from recycling flakes.

First of all, the composition of a specific batch of mixed recycled plastics (whether they are post-industrial or post-consumer) must be determined, together with the origin and potential contaminations such as coolant, paper, wood, metal, small amounts of other polymers, etc. Subsequently, different test were conducted within this research project, these are: Fourier-transform infrared spectroscopy (FTIR) to detect the type of polymers in the waste stream, mass-measurement method to define the melt flow index (MFI), a density kit to gravimetrically measure the density, differential scanning calorimetry (DSC) to obtain thermal properties, notched Charpy impact test leading to the impact resistance, a bending test to retrieve the flexural modulus, and finally a tensile test with an extensometer to calculate tensile strength and Young's modulus. More detailed information about the technical tests are not part of this paper's scope, instead the authors refer to earlier work (Hubo & Ragaert, 2014; Van Kets, Van Damme, Delva, & Ragaert, 2016). To conclude, the results and data can be transferred to the technical datasheet of each material.

C. Translation to designerly descriptions

The designer's approach or 'language' is characterised by fuzzy labels and descriptions. Consequently, the numerical data is not sufficient for IDE to start their design process with. We argue that the technical properties should be further explored and translated into designerly descriptions that they can work with during the MDD step of technical characterisation. We propose this can be done through an elaborated **technical translation** in order to formulate the implications, opportunities and limitations for the design process. This implies that the industrial design engineer will look for familiar and well-known materials that they already have experience with. Similar characteristics will be formulated as 'recycled material x sounds like known material y', or 'the strength of recycled material x is comparable to virgin material y'.

Additional steps on a user-centred level

After completing the technical characterisation, the recycled material will be explored from a user-centred perspective. To respond to the designer's approach – that is indispensable for designing material experiences – a set of different **samples** of this material has to be passed to the industrial design engineer, along with equivalent samples of well-known plastic materials to compare with. However, these samples should be **shape-independent** in order to exclude associations to similar shaped products. Therefore, we will use the test samples from the engineering lab (flat test bars), supplemented with the sprues that show differences in surface finishes of the mould.

In the case of the recycled plastics of this project, their technical material properties are still situated within the limits of most plastic materials that designers are familiar with. Hence, we argue that the *Experiential Characterisation* is a very crucial step for IDE to differentiate the recycled material on the market. Especially in the context of recycled plastics (that are mostly deriving from consumer waste), their perception by **end users or consumers** is considered as a bottleneck, and should therefore be explored early in the MDD process. This dualistic approach makes it possible to compare and incorporate the vision of both designers and consumers. To facilitate this process, we provided two formats for a first sensorial and interpretive exploration, building upon the sensorial Likert-scales of Karana et al. (Karana, Hekkert, & Kandachar, 2010) and comparable to the creation of personas. These input forms serve to break the ice, engage consumers and to introduce potential material descriptions that can be further discussed in interviews.

In addition, we want to encourage designers to compose supporting **Experiential Moodboards** for communication and inspiration. These inspirational moodboards can visualise a combination of both observed or intended material experiences that can be interesting in the idea generation.

Applying the MDD

With the two discussed adaptations in mind, the next Section will explain the set-up for the expected application of each step of the Material Driven Design (MDD) approach to future cases within the Design from Recycling project. As this project aims to design with and for relatively unknown or new, yet fully developed recycled plastic materials, it can be positioned in the second scenario as distinguished by Karana et al. (2015). As mentioned in the problem definition, the materials within our research project are not yet linked to settled meanings, user experiences or application areas, thus offering designers great freedom to introduce new material identities.

MDD Method Step 1 – Understanding the material: Technical and Experiential Characterisation

The MDD approach is initiated by the collaborating engineering lab that provides the technical datasheets and samples for the designers. Then, three simultaneous steps are performed in order to fully understand the given recycled plastic and to explore its unique opportunities. The *Technical Characterisation* will be continued by the designers through tinkering with the provided material samples in order to interpret the numerical data that is proposed by the engineering lab. In contrast to the previous, controlled conditions, designers are now encouraged to drill, bend, pull, break, and play with the materials themselves. Due to the specific context of industrial processing techniques, mould making and high processing temperatures, tinkering is limited to the material samples only. Despite the fact that this research project initiated from the application of extrusion and injection moulding, we would still encourage designers to look beyond this restriction and explore other industrial processes as well, such as rotation moulding, structure foam moulding etc.

Furthermore, we propose to visualise the main technical properties in reference tables and graphs in order to find links with other well-known materials and their application areas, leading to the interpretation of the general, practical significance of each property and thus, give meaning to the numbers. For example, a low E-modulus implies that the material is flexible and – in the case of polypropylene – is therefore typically used in integral hinges. Likewise, the combination of two properties such as cheap and light can position recycled plastics near materials such as concrete or cork, leading to new application fields. Finally, this exploration should lead to insights concerning the questions in Figure 5.

Technical characterisation of the material (TCM)	
Q1	What are the main technical properties of the material?
Q2	What are the most convenient manufacturing processes to form the material?
Q3	What about other manufacturing processes? How does the material behave when subjected to other processes?
Q4	What are the technical constraints of the material?
Q5	What are the technical opportunities of the material?

Fig 5. Guiding Questions for Technical characterisation (Karana et al., 2015).

However, when introducing the recycled plastics within this project as new and unique materials in the market, designers must first discover the experiential identity of each material, which can be done through the *Experiential Characterisation*. Giaccardi and Karana (2015; Karana et al., 2015, p. 41) state that “the designer should reflect on four different experiential levels: **sensorial**, **interpretive** (meanings), **affective** (emotions), and **performative** (actions, performances)”. Due to the industrial process limitation, designers cannot create samples themselves; our recycled plastics are no DIY materials (Rognoli et al., 2015). Hence, varying in aesthetic qualities is rather limited to shape and mould finish in this case. However, we suggest that they use the moulded sample set of the engineering lab to explore how it is being received not only by designers but also by end users or consumers, using the proposed sensorial and interpretive exploration scales. Through focus groups and interviews the material samples can be further discussed to dig deeper in the matter and find other meanings, emotions and actions, specifically within a recycled/sustainable context. Are the materials actually perceived as recycled plastics? Are they even associated with other recycled materials? This exploration should answer the questions in Figure 6 and its outcome can be brought together in several Experiential Moodboards (Figure 7).

Experiential characterisation of the material (ECM)	
Q1	What are the unique sensorial qualities of the material?
Q2	What are the most and the least pleasing sensorial qualities of the material (according to end users)?
Q3	Is the material associated with any other material due to its similar aesthetics?
Q4	How do people describe this material? What kind of meanings does it evoke?
Q5	Does it elicit any particular emotions – such as surprise, love, hate, feat, relaxation, etc.?
Q6	How do people interact and behave with the material?

Fig 6. Guiding questions for Experiential characterisation (Karana et al., 2015)

In the case of this research project, several pre-settled meanings were detected in a preliminary exploration such as the imperfections in the materials that express uniqueness and surprise, rather than an ecological impression. Another peculiar aspect is the lack of freedom regarding possible colours of the mixed recycled materials, which are usually black or dark grey due to the mix of all kinds of colours.

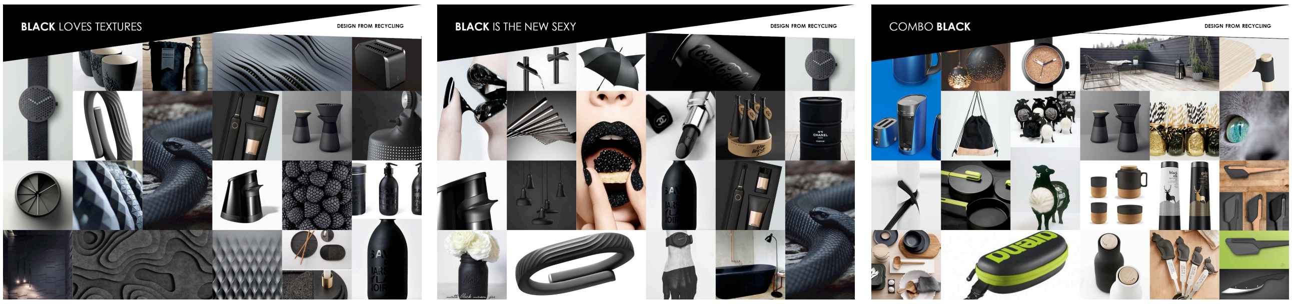

Fig 7. Experiential Moodboards exploring the possibilities of 'black'.

As previously mentioned in the existing approaches Section, the Relation Tool by Van Kesteren (2008) can also be useful in this phase of the MDD process. In this way, the main sensorial attributes can be linked with various technical properties. This implies that designers can explore what sensorial attributes can still be modified up to a certain level later on in the design process to better fit the intended material experiences (e.g., the glossiness or surface texture partly depends on the mould finish).

Finally, insights through both the technical and experiential characterisations can be linked through the step of *Material Benchmarking* that concerns the questions of Figure 8. In this step, designers have to search for similar materials with regard to look, emerging experiences and sensorial effects of processing techniques in order to summarise their areas of application. The conclusions concerning the questions in Table X can be presented by means of diagrams and/or additional moodboards.

As our project's materials are waste-based, other waste materials and their applications can be explored and correlation might be found in terms of imperfections, limitation of black colour, etc. In addition trends and strategies concerning waste recycling, circular economy or life cycle thinking can be mapped as well.

Material benchmarking (MB)	
Q1	What are the applications for which the materials have been applied so far?
Q2	What kind of activities do these applications support and why?
Q3	What kind of technical properties do others emphasize?
Q4	What kind of experiential qualities do others emphasize?
Q5	Is there any specific design approach, strategy, business model, or trend the material is bond to?

Fig 8. Guiding questions for Material benchmarking (Karana et al., 2015)

MDD Method step 2 – Creating Materials Experience Vision

Based upon the output of the technical and experiential explorations, the design intention can now be articulated in a '**Materials Experience Vision'** as stated by Karana et al. (2015). This statement should answer the questions in Figure 9, and it can be formulated as 'the material - does what - with whom - to achieve?'. To compose this tagline, a final decision should be made on whether a settled meaning will be preserved or a novel meaning will be exploited in a future product. Consequently, it can be considered as the unique selling proposition that designers will use as their inspirational backbone to reflect on the material's purpose throughout the further design process and idea generation.

Materials experience vision	
Q1	What are its unique technical/experiential qualities to be emphasized in the final application?
Q2	In which contexts would the material make a positive difference?
Q3	How would people interact with the material within a particular context?
Q4	What would the material's unique contribution be?
Q5	How would it be sensed and interpreted (sensorial & interpretive levels)?
Q6	What would it elicit from people (affective level)?
Q7	What would it make people do (performative level)?
Q8	What would be the material's role in a broader context (i.e., society, planet)?

Fig 9. Guiding questions for Materials experience vision (Karana et al., 2015)

Within the specific cases of this project, two opposite design strategies can be chosen to support the Materials Experience Vision. On the one hand the recycled character of the materials can be displayed and enhanced - c.f. the value of imperfection (Salvia, Ostuzzi, Rognoli, & Levi, 2011) - on the other hand the quality of the industrial possibilities (as similar to virgins) can be reinforced, without emphasising the recycling background.

MDD Method step 3 – Manifesting Materials Experience Patterns

In the third step, Karana stated that designers should extract two or more key meanings from their Materials Experience Vision and explore the link with formal properties (i.e. shape and processing techniques) through brainstorming sessions and the Meaning Driven Materials Selection (MDMS) tool (Karana et al., 2010). For example, people might appraise materials as unique and robust due to imperfections or a speckled surface. We propose to rely on links and material examples that are already available in literature and previously conducted MDD projects. We would suggest to match this available information with the industrial context of our project, to reason with the formal properties.

MDD Method step 4 – Creating Material/Product Concepts

On the basis of the vision statement and the target group, various application areas can now be identified, leading to a brainstorm about possible future **material-product concepts**. Subsequently, the regular design process can again be followed, consisting of trade-off, concept development, and detailed engineering. As Karana et al. discuss (Karana et al., 2015), in Scenario two with a fully developed material, the designer can only manipulate or influence its sensorial qualities through different shapes and mould finishes for surface quality, texture and gloss. To ensure that the product concepts still attribute the intended meanings and experiences, the involvement of end users is again essential in this design phase. For the detailed engineering, feedback is needed from the engineering side about technical considerations and design guidelines arising from the defined processing techniques. In case of injection moulding with mixed recycled plastics, this may involve a greater wall thickness, more reinforced ribs, etc. In addition, 3D strength simulations with CAD software are useful to test the performance and mechanical strength before even producing the mould.

Discussion

This paper presents the first steps within the ongoing research project 'Design from Recycling', which aims to support engineers and designers to apply mixed recycled plastics in high quality products. However, the suggested MDD approach still needs to be tested, reworked and verified through an iterative process of cases, as will be conducted in the progress of this research project. In this respect, during the progress of the case we may encounter the need to carry out the third MDD step more extensively after all.

First explorations within the initiated material cases showed that there are definitely product applications possible for these recycled materials as long as industrial design engineers are cautious about the technical properties that lead to design restrictions. Consequently, these materials should rather be differentiated on the user-centred level of experiential characteristics. As mentioned before, the strategy of 'the value of imperfection' can be further explored in order to elicit unique material experiences.

In order to further emphasise the sensorial attributes and technical properties on the one hand, and the designerly translation of these technical properties on the other hand, a more extensive sample set would be desirable. Within this research project, an injection mould will be developed for a material 'determiner', physically showing the most important technical (and sensorial) aspects for designers, such as glossiness, stiffness, shrink cavities, minimal wall thickness, etc. This would result in a hands-on resource for designers to understand the recycled materials and one-on-one compare their qualities with known virgin plastics, beyond what is possible through traditional datasheets.

Conclusions

This paper aimed to clarify the setup of a methodological approach that would facilitate the design process with mixed recycled plastics as a starting point. 'Design from Recycling' (DfromR) is a new approach within the concept of circular economy, which examines to what extent a new product can be produced from an existing flow of recycled polymers, and the design specifications that this entails.

To date, the material engineers within this research project are at the point of being able to recycle and industrially process mixed plastic waste through extrusion and injection moulding. However, an impasse is experienced at the point of implementing these new materials in designs; they often fail when introduced to the competitive market. To address this issue, the authors explored the existing Material Driven Design (MDD) methodology that also puts a new materials as the starting point of a design process, and interpreted how its four steps can be applied to the specific material cases of the Design from Recycling project. Due to the context of industrial processing at the engineering lab, some challenges had to be accommodated throughout this reasoning process, both on a technical and a user-centred level.

The proposed adaptations include a condensed list of relevant materials properties for all project partners; a survey to verify their relevance for industrial design engineers; a comparison approach for recycled versus virgin plastics; an elaborated technical characterisation at the engineering lab by means of standardised tests; a technical translation to designerly descriptions; the development of shape-independent materials sample sets; an end-user (consumer) evaluation of the experiential material characteristics; and finally, experiential moodboards for communication and inspiration throughout the MDD process.

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