Design for and from Recycling: Towards a designer guide for plastic packaging

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Abstract: Recycling is proposed as a solution to the ever-growing waste problem, and the aim to keep as much material value in the system has reached packaging designers. Designers can pick numerous standards and guidelines for Design for Recycling, explaining exactly what design decisions to take in order to make packaging recyclable. However, an overhaul of the general design approach is necessary to fully close the material loop: recycled materials should be used in packaging. This phenomenon of Design from Recycling is currently barely addressed in literature. The present research aims to expand the knowledge on Design from Recycling while considering the Design for Recycling standards, so no compromise needs to be made on recyclability. In doing so, this paper shapes a novel focus on "Design for and from Recycling". The research builds on a literature review, complemented with expert interviews. Based on this, guidelines are proposed, which are then tested and verified in a design process. The result of the study is a first set of guidelines that proves to be useful in packaging design. Although these guidelines need further development before they can be used in practice, this research indicates the urgency and relevance of doing so.

Keywords: Packaging design, recycling, sustainability, circular economy

1 Introduction

Plastic – and more specifically, plastic packaging – is responsible for an ever-growing waste problem. Plastics have taken up such a prominent role in our modern society. The Ellen MacArthur Foundation[1] describes that despite its disadvantages, "both the likelihood and desirability of an across-the-board drastic reduction in the volume of plastic packaging used is clearly low." In an effort to solve the plastic waste problem, plastics recycling has become common around the world and has even found its way to the packaging industry. Here, many companies have pledged to make their packaging suitable for recycling,[2-4] and many guidelines for Design for Recycling (DforR) have been developed.[5-8] However, although this is a relevant first step, it is not enough to close the material loop. For this to happen, the recycled material must also be used in new products and packaging must be designed accordingly. This is done in Design from Recycling, as introduced by Veelaert, Hubo, Du Bois, Ragaert.[9]

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In this paper, the concept of Design for and from Recycling (Df2R) will be explored, aiming to add Design from Recycling guidelines to the already existing Design for Recycling guidelines, to make sure the recyclability will not be compromised. The goal of the paper is not to provide a full comprehensive list of guidelines, but rather to indicate that this is an urgent and relevant topic that needs further research. The guidelines that are proposed serve as an example and a head start for future research. In this paper, only a selection of the guidelines that were found are published, the full list can be requested from the authors.

The research is performed as shown in Figure 1, and the paper is structured in a similar way. The first step was to analyse current literature on the topic, then asking a group of experts for verification and any additions. Next, a product packaging is redesigned to see if the guidelines can actually help designers and see what guidelines could be found through a design process. Finally, the guidelines are compared to see if any guidelines contradict each other. The approach can be used as an example for further research.

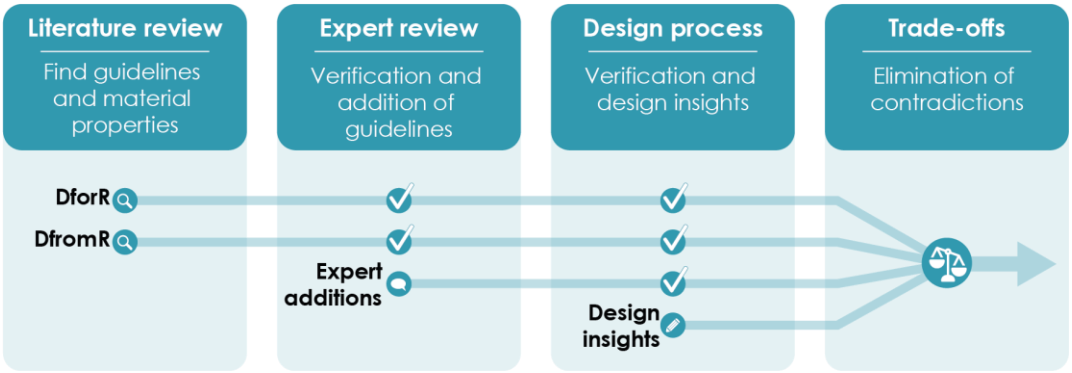

Figure 1. Research steps

2 Literature review

2.1. Design for Recycling

In order to understand how to design for recycling, one must first know what makes a packaging recyclable. According to the Ellen MacArthur Foundation,[10] "a packaging or packaging component is recyclable if its successful post-consumer collection, sorting, and recycling is proven to work in practice and at scale." This definition deems part of plastic packaging waste as 'unrecyclable'. For example, PVC and PS are currently not collected for recycling (in the Netherlands),[6] black material can't be detected by a NIR scanner[8] and hence will not be sorted.

A clarification that is made in the same definition[10] is that "packaging for which the only proven way of recycling is recycling into applications that do not allow any further use-cycles (e.g. plastics-to-roads) cannot be considered 'recyclable packaging'." These end-of-loop uses are often the fate of mixed materials,[11] originating from multi-material packaging, or non-LDPE films[12] and would thus make these types of packaging unrecyclable as well.

The goal of Design for Recycling is to avoid that the packaging becomes unrecyclable and to improve the quality to allow for as many future use cycles as possible.[12] Many institutes have

published guidelines that will help brands to redesign their packaging.[5,6,8,13] These guidelines vary from material choices (**"Use commonly recycled materials: PP, PE and PET"**[6] and **"Design mono-material"**),[8] to visual design choices (**"Use neutral, light colours"**),[13] and dimensions (**"Make packaging bigger than 5cm ⌀ and smaller than 5L"**).

2.2. Design from Recycling

While Design for Recycling can improve the quality of the recyclate, if we are to move towards a circular process, the current recyclate also needs to find a purpose in new products. To do so, one must first know how the material properties of recyclate currently deviate from virgin material.

Firstly, the material is often contaminated, which reduces the quality. Contamination with polymer,[14,15] metals,[16] paper[17] and non-meltable parts[18] can deteriorate the material stiffness, strength and ductility. Besides, its past life-cycle can reduce qualities like its melt-flow index (MFI) and ductility,[19] due to heat, oxygen and light.[20,21] The variety of additives that are introduced into polymers to get the required specifications, accumulate in the recyclate, leading to unwanted behaviour or material degradation.[22] The variety of colours of the original packaging make the recyclate a dark grey colour, which is much less demanded,[23] where the non-meltable parts can appear as flecks.

For Design from Recycling, no clear-cut guidelines have been published. Hence every inferior material quality has to be tackled separately. To overcome the brittleness, **fast cooling of the material during processing** can be a solution.[24] A higher MFI means that instead of extrusion or blow moulding, **the material is more suitable for injection moulding**.[25] **Wider runners and sprues, and increased wall-thickness**[26] can prevent non-meltable parts from blocking the flow during injection moulding. The visible contamination can be used for **branding its unique look**,[27] or **textures**[28] **or an outer layer of virgin plastic**[29] can be used to hide the flecks. Where in some instances a white/neutral recyclate is available,[30] it is still important to **use dark or coloured recyclate where possible**.

2.3. Challenges

Although there is little literature available on the topic of Design from Recycling, it is important to notice that recycled plastic materials (rPM) are currently barely used in packaging design. This section will cover the challenges that brand owners face when trying to introduce recyclate into their product portfolio. Most of these challenges can be traced back to the immaturity of the plastic recycling chain, compared to the recycling chains of other materials such as glass and paper.[31]

First, the value for money of virgin plastics exceeds the value of recycled plastics. The quality of recyclate is inevitably lower than the quality of virgin plastics, for reasons described in the previous section.* Besides, goals are set for the quantity of recyclate,[33] but not for the quality. With the low oil-price (as of May 2021),[34] resulting in low prices for plastics,[35] the processing

* Chemical recycling is an exception to this rule, as this process can return the material to the same quality as virgin material.[19] However, as this is not yet widespread or economically viable[32] this will be left out of consideration.

costs for recycled plastics remain the same. This has created the situation that rPM is has become more expensive than virgin plastics.[36]

Another problem is communication. Innovation is required within the entire recycling chain, and misalignment between e.g. producer and post-processor can reduce the recycling performance.[37] To try to overcome this, cooperative initiatives (e.g. Plastic Pacts) have been set up, where collaboration and sharing knowledge are the key motivations to join such an initiative.[38]

3 Interviews

To get additional context and information on the research topics, expert interviews were performed. Six experts from the recycling industry and research were interviewed about the status of plastics recycling and what could be improved. The interviewees represent different perspectives from the recycling chain of both PET and HDPE recycling, and academics both in the recycling process and in packaging design.

Four interviews were performed via (video) call, and two others were performed by email. The email interviews were structured, whereas the (video) calls were semi-structured interviews. The interviews were performed in Dutch (as this is the native language of all experts), recorded and transcribed, then relevant statements were neutrally translated to English to be used in-text. Apart from the statements shown in this section, the experts also pointed out new topics that could be researched and are hence already covered in the literature section.

All interviewees agreed that the efficiency and results from the plastics recycling, as well as the use of recyclate in packaging is currently subpar. There is little incentive for companies to use rPM in their products, and it would be preferable to "have regulation that gives financial encouragement to promote use of recyclate" (Interviewee B). This could indeed overcome the price disadvantage, mentioned in the previous section. Interviewee C pointed out that the focus of packaging designers should change: "they only look at the consumer problem and do not consider recycling." Another problem is that the academic interest in plastics recycling has only started around five years ago. This leads to the problem that "all knowledge on recycling that is currently available, is based on industrial experience, instead of scientific facts." (Interviewee D). The complexity of variations in polymer properties of virgin plastics, make it difficult to predict what the recycled plastics can be used for, according to Interviewee E.

4 Design process

In the design process, the guidelines developed through literature and interviews were used to improve the recyclability and application of recyclate in the packaging. For this redesign case study, a non-food fast-moving consumer goods packaging was considered, namely an AXE shower gel bottle. This type of product is chosen because of the challenging set of requirements for the material (both technical and visual). The shampoo bottle is chosen because it is a non-food product and thus allows for easier implementation of recyclate.

There are two general designs of AXE shower gel bottle on the market, as shown in Figure 2. Both designs have been tested on recyclability using the RecyClass assessment.[39] Design A

scored the second-highest score of B, because it is made mono-material and the light colour of the bottle will not cause discolouration in the recyclate. Design B receives the lowest possible score of F, because of its dark colour and multi-material bottle.

Figure 2: Two variations of AXE shower gel bottles. Design A (left): the translucent bottle, design B (right): the black bottle. Edited from axe.com.[40]

The redesign, as shown in Figure 3, has been made using the guidelines. The bottle is made of **dark recyclate**. The bottle, cap and back label are all made of the same polymer type, resulting in a **mono-material** design. This **material (PP) is also collected for recycling**. Besides, a **texture is added to hide any visual contamination**. The added benefit of addi**ng the texture in a smart way, eliminated the need for a front label**. This is a design guideline that was found through the design process. All of these improvements have led to an improved RecyClass score of A+++, the highest possible score, and thus an improvement of both original designs.

Figure 3: The redesign of the AXE shower gel bottle.
NB: The difference in colour is a result of the texturing, no pigments are added.

The design process shows that the guidelines indeed allow for designing to improve recyclability and use of recyclate. It has also shown that apart from what could be found in literature, two additional guidelines could be added. The first one is to use embossing or textures to replace the label, where the second is not discussed yet. During concept development, two alternative designs were thought of (Figure 4). Concept 2 and 3 are both designed in such a way

that the bottle is not required to be flexible, meaning that a brittle material would still be suitable. As in the end a material could be found with sufficient ductile behaviour, the other concepts were disregarded, but this does mean that the guideline **"Design for rigid parts that do not require bending"** could be added as a guideline to prevent brittle fracture.

Figure 4: The three concepts, where 2 and 3 were the alternatives to the chosen concept 1.

5 Design for and from Recycling

The last step that was performed to get to the initial list of guidelines, was to look for contradictions between guidelines that were found, in order to overcome them. One such contradiction is between the guideline "Use neutral, light colours", and "Use dark recyclate", this can be resolved by changing it to "Do not use pigments". Another inconsistency is between "Design mono-material" and "Add an outer layer of virgin plastics." Changing the latter to "Use in-mould labels of the same polymer type as the recycled plastic within" resolves the inconsistency.

This results in the list of guidelines as shown in Table 1. Designers can use them to change towards Df2R without having to do all the research themselves, in the same way as they are currently using DforR guidelines to increase the recyclability.

Table 1. List of initial guidelines

Guideline	Based on
Use commonly recycled materials: PP, PE and PET.	DforR
Design mono-material.	DforR
Use recycled material for eco-marketing.	DfromR
Add an uneven texture to mask the visual contamination.	DfromR
Add no pigments to the available material.	Df2R
Use textures, embossing or engraving to replace the label.	DfromR
Use an outer layer of virgin plastics of the same polymer type as the recycled plastic within.	DfromR
Design for rigid parts that do not require bending.	Design
Make packaging bigger than 5cm and smaller than 5L.	DforR
Fast cooling during processing.	DfromR
Use wider runners and sprues.	DfromR
Use recycled material for injection moulding.	DfromR

6 Conclusions, discussion and recommendations

This research has made a first step in setting up guidelines to Design for and from Recycling, to make plastic packaging recyclable, while being made of recycled material. As pointed out in the introduction, the aim of this research was not to present a finalised set of guidelines, but to 1) show that it is a relevant topic to perform further research on and 2) that it is possible to use literature research and a hand-on design approach to come to a first set of guidelines. As the attention for recyclability has led to many guidelines and companies changing towards recyclable packaging, shifting the focus to including recyclate in packaging will also lead to more recyclable content included.

This research should be continued in order to set up a complete and comprehensive list of guidelines. For this, the currently used process serves as an inspiration for the future research processes. However, as the depth of study will increase in future studies, more details can be included as well. For example, samples of recyclate could be examined to get a better understanding of the materials, or the resulting guidelines could be further validated by a wide range of industry specialists.

7 Final notes

As this research is only the very start in developing guidelines for Design for and from Recycling (Df2R), do not hesitate to contact the authors. We would be glad to get feedback on the current work or hear what topics should be addressed in further studies. Consider this paper as an open invitation to perform further research on this topic.

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