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Introducing the Reshape strategy: Preserving material integrity

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Abstract: One of the significant challenges of today's society is the unsustainable overconsumption of resources, coupled with the generating of enormous amounts of waste. European manufacturing produces over 230 million tons of waste annually, much of which remains unaddressed within existing circular economy frameworks that predominantly focus on post-consumer waste. This paper introduces the Reshape strategy, which aims to respect, incorporate, and utilise pre-consumer industrial waste to create new products, thereby reducing dependence on virgin materials. Positioned within current R-frameworks, the Reshape strategy addresses a theoretical gap in circular economy literature, where the Recycling strategy is commonly used and Reuse often being misapplied, leading to theoretical ambiguity. Reshaping emphasises the extension of material lifetimes rather than downcycling through recycling. Therefore, this research explores the potential of industrial waste as a resource through 19 case studies from a Danish research project focused on designing with industrial waste materials. The findings emphasise the inherent qualities of industrial waste and outline activities within the Reshape strategy that leverage the material's integrity in terms of function, form, or material composition, thereby extending its lifetime. By leveraging these qualities, this study contributes theoretically to the circular economy by refining terminology and advancing the understanding of pre-consumer waste within circular systems. The Reshape strategy aligns with circular economy principles, aiming to keep materials in productive loops while addressing the significant untapped potential of discarded materials.

Introduction

The circular economy concept revolves around an industrial regenerative system to eliminate waste through intention and design. It tackles resource scarcity, which is one of today's fundamental challenges. (Ellen MacArthur Foundation, 2013) Various R-strategies and ladders are defined to support the industry and designers in decreasing the discarding of materials and resources. Frameworks such as the 6R Framework (Sihvonen & Ritola, 2015) and the 9R Framework (Potting et al., 2017) propose strategies to achieve less resource and material consumption. (Kirchherr et al., 2017) These frameworks extend the waste hierarchy defined by the European Parliament in the 2008/98/CE directive, which includes Prevention, Reuse, Recycling, Recovery, and Disposal (Figure 1) (European Parliament, 2008). The 4R Framework of Reduce, Reuse, Recycle, and Recover is much in line with the waste hierarchy, only leaving out disposal (Kirchherr et al., 2017). The top strategy of Prevention/Reduce treats how not to generate waste, whereas the latter stages of the hierarchy treat waste at a product stage that has gone through a consumer. Hence, the

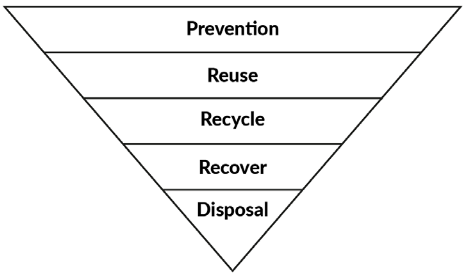

Figure 1. Waste hierarchy (European Parliament, 2008)

hierarchy and 4R Framework assumes no waste treatment between prevention and the consumer stage.

However, waste also emerges at a pre-consumer stage, where materials are discarded in the manufacturing of new products. European manufacturing companies generate over 230 million tons of industrial waste annually (Eurostat, 2022), occurring at the manufacturer stages in the Butterfly diagram by Ellen MacArthur Foundation (Figure 2) (Ellen MacArthur Foundation, 2019). In standard practices, discarded materials are often recycled, causing downcycling of the material

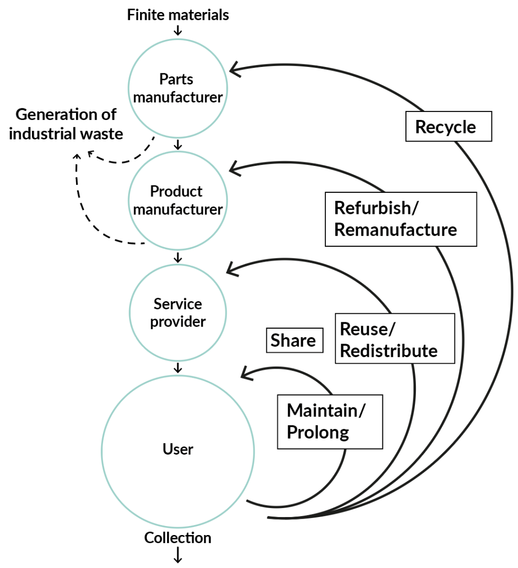

Figure 2. The Butterfly Diagram adapted from (Ellen MacArthur Foundation, 2019)

(Awogbemi et al., 2022). However, energy and time have been put into the form and composition of the materials to fit a specific intention before they were marked as waste and thus discarded (Szaky, 2014). Utilising this as a substitute for virgin materials in new product designs adds a design perspective to the discussion on material utilisation with emphasis on respecting and including material discards to benefit from the craftsmanship, time, and energy that has been put into processing the materials. It is challenging, as materials provide technical functionality and personality to a product (Ashby & Johnson, 2014), which will be affected when the material is discarded. It may result in a new materials aesthetic that includes imperfect materials (Rognoli & Karana, 2014). Intervening industrial waste's intrinsic potential by extending the lifetime of the material into the resource of new products may lead to a 40% reduction in cost and 67% energy savings compared to recycling (Ali et al., 2019). Thus, there is great potential in a circular strategy that reintegrates discarded materials pre-consumer in new manufacturing cycles before they reach recycling or disposal.

Through the work of examining cases from a Danish research project on designing new products from industrial waste, confusion has emerged in trying to position the activity of leveraging industrial waste in the waste hierarchy (Figure 1) or any of the currently defined R-strategies, without causing theoretical ambiguity. This confusion aligns with other researchers who state that the terminologies of the circular strategies are understood and applied differently in practice (Dokter et al., 2021), potentially resulting in a collapse of the concept if the definitions are not coherent (Kirchherr et al., 2017).

We identify a theoretical gap within the literature on waste treatment and -hierarchy in the circular economy and argue for a missing, yet important, area with the wasted materials that have not yet been in circulation with consumers. Therefore, the research aims to establish a circular strategy that treats the activity of leveraging industrial waste materials and assesses its position in existing circular frameworks. The objective is to understand the activity of elevating the opportunities in discarded materials from a design perspective, aiming to include more materials in manufacturing, not least formerly discarded materials. Thus, the research question is: **What is the circular strategy for leveraging industrial waste, and how does it support the inclusion of discarded materials in new products?**

Extending lifetime of materials and products

Circular R-strategies

The R frameworks are core principles of the circular economy (Kirchherr et al., 2017). Frameworks beyond the 4Rs, such as the 9R Framework, offer more nuanced strategies aimed at maintaining the a product's primary function, thereby preserving its highest integrity level and minimising processing time and energy (Potting et al., 2017). Circularity increases as strategies are positioned higher in the hierarchy. In the 9R Framework, strategies for smarter product use and manufacturing reduce the addition of natural resources in a product chain, corresponding to the Reduce strategy in the simpler 4R Framework (Table 1). This is also seen as narrowing the resource loop regarding efficiency (Bocken et al., 2016). Strategies below this level treat the circularity of products and parts at the consumer stage or post-consumer to extend the lifetime. (Potting et al., 2017) Hence, Reuse, Repair, Refurbish, Remanufacture, and Repurpose all concerns slowing the resource loop by extending the use period of products at the consumer stage, compared to the Recycle strategy, which closes the loop between post-use and manufacturing (Bocken et al., 2016).

4R Framework (Kirchherr et al., 2017)	**9R Framework** (Potting et al., 2017)	
Reduce	**R0 Refuse** Make product redundant by abandoning its function or by offering the same function with radically different product.	Smarter product use and manu-facturing
	R1 Rethink Make product use more intensive (e.g. through sharing products, or by putting multi-functional products on the market).	
	R2 Reduce Increase efficiency in product manufacture or use by consuming fewer natural resources and materials.	
Reuse	**R3 Reuse** Reuse by another consumer of discarded product which is still in good condition and fulfils its original function.	Extend lifespan of product and its parts
	R4 Repair Repair and maintenance of defective product so it can be used with its original function.	
	R5 Refurbish Restore an old product and bring it up to date.	
	R6 Remanufacture Use parts of discarded product in a new product with the same function.	
	R7 Repurpose Use discarded product or its parts in a new product with a different function.	
Recycle	**R8 Recycle** Process materials to obtain the same (high grade) or lower (low grade) quality.	Useful application of material
Recover	**R9 Recover** Incineration of materials with energy recovery.	

Table 1. The 4R and 9R Framework, definitions from (Potting et al., 2017, p. 5)

Figure 3 illustrates the application of the 9R strategies at relevant points in a product chain, providing an overview of processes and chain actors, and identifying intervention points to enhance circularity. (Potting et al., 2017) The illustration includes resource inflow and the outflow of waste. We have added the waste streams, as they were absent from the original figure.

In summary, the Butterfly diagram, 9R Framework, and the Product chain figure overlook industrial waste, as they focus on the product and consumer stages rather than the pre-product and pre-consumer stages. This results in a confusing mix of definitions in circular economy and waste treatment research (Singh et al., 2017). For instance, "reuse" is defined in post-consumer loops and typically refers to a product being reused by a second owner but with the same function (Potting et al., 2017). However, studies on utilising industrial waste at a pre-consumer level also describe this as being "reuse" (e.g., (Pacelli et al., 2015; Sander et al., 2024). While the intention of using the resource again at the same integrity level may be similar, the multiuse of the term creates confusion.

Whilst the descriptions of the post-consumer strategies in the frameworks that cover extending the lifespan of products may also be applicable at a pre-consumer stage, it adds to the confusion if these are to be mixed. We propose streamlining the definitions to separate strategies pre- and post-consumer for further theoretical development. The principal difference between pre- and post-consumer is the starting point of the strategy, whether it is a product that has been used (post-consumer) or not (pre-consumer). An additional potential layer of confusion is introduced when mixing resource states in the strategies, thus focusing on particles (including materials) or products. Blomsma and Tennant (2020) propose the Resource States framework to clarify the differences and connections with circular strategies (Blomsma & Tennant, 2020).

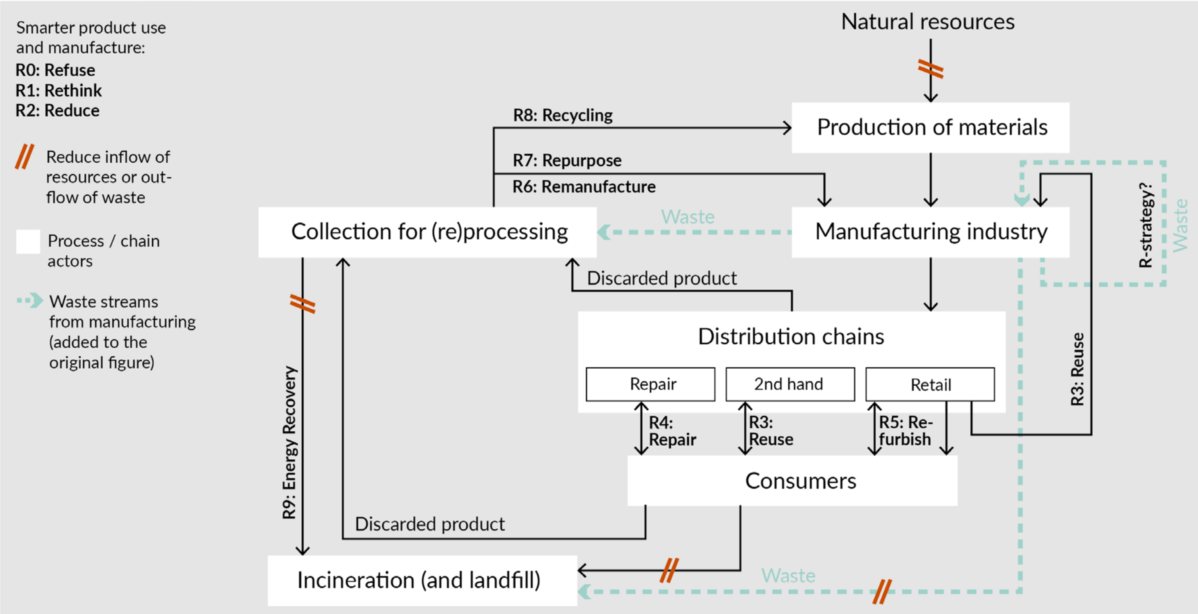

Figure 3. Product chain with applied R-strategies, including the introduction of waste streams, adapted from (Potting et al., 2017)

Leveraging on integrity level

Industrial waste, or manufacturing waste, comprises various materials that emerge from manufacturing products and are discarded (Awogbemi et al., 2022). In some scenarios with certain conditions, industrial waste may be considered a by-product if a secondary product can be made from it (European Parliament, 2008). The two typical typologies of industrial waste are scraps or rejects (Pacelli et al., 2015), covering both off-cuts and rejected objects in quality control. According to the situation, these heterogeneous materials vary in size, shape, and quantities, as well as mechanical and sensorial properties (Feast & Laursen, 2023).

These characteristics define the material's integrity level. The integrity level is described with various focuses in the current literature on a post-consumer stage, such as the 9R Framework that focuses on maintaining the function of the products (Potting et al., 2017), while others describe it with the level of disassembly and identity (Sihvonen & Ritola, 2015). Upcycling literature views a product's value in terms of composition, form, and intention. The upcycling activity leverages the form and composition but not the intention. (Szaky, 2014) These three levels of function, form, and composition can also describe the integrity level of discarded materials at a pre-consumer stage, framing the potentials based on prior material processing. For example, discarded wooden floorboards due to unacceptable colour variants or knots in one manufacturing line may still be used for flooring in another company, hence leveraging the original function/intention of the material. If this cannot be leveraged in a new product design, maybe the form and size of the boards can. If this is not possible, the material composition of solid wood may be leveraged into smaller trays.

In summary, we argue for a missing strategy to leverage the integrity level of the discarded industrial material based on the situation and business in which it may be used. From a design perspective, this study investigates industrial waste to identify how to include this in new product design, hence looping the flow of wasted materials back into the manufacturing industry. Additionally, the details of this circulation loop strategy are investigated to support material inclusion for designers.

Method

This multiple-case study assesses 19 cases from a two-year exploratory research project on how to design from industrial waste materials (Table 2). The cases involve various waste materials from Danish small/medium-sized manufacturing companies where designers have assessed the materials and developed new product proposals based on the specific waste. This study investigates if we, through the design competence, can create smaller loops of resource utilisation to retain most of the value in the discarded materials without unnecessary use of both time and energy, thereby respecting the materials at their integrity level. Hence not resort to recycling as the preferred waste management.

The collected data comprises field notes from start-up meetings, status meetings, and final meetings. Additional visual material developed along the design processes has been collected for all the cases. The cases are analysed and mapped against using the materials in the new product design(s) to assess how the integrity level is leveraged.

#	Discarded material	Description	New product proposal(s)
1	Leather (from upholstery industry)	Pieces of upholstery leather, rejected due to scars, imperfections and small sizes	a) Door handle, b) cushion, and c) notebook cover
2	Ceramics (from kitchen tabletops)	Sink or cooking plate size, offcuts	Soap display
3	Metal (from roofing)	Profiled metal sheets, rejected due to scratches an incorrect adjustment of machinery	Facing for a recycling centre building
4	Wood (from kitchen tabletops)	Offcuts from sink and/or cooking plate	Side table
5	Textile (from clothing industry)	Trousers, rejected for wrong colour or size	Tote bag
6	Concrete (from building industry)	Smaller sample of concrete for testing consistency before casting elements	Table and bench set
7	Wood (from flooring)	Solid wooden floor, rejected due to knots, cracks, and other imperfections	Indoor door
8	Acrylic (from automotive industry)	Full and flat sheet size, rejected because of air bubbles and scratches	Bench
9	Textile (from furniture industry)	Offcuts of textile pieces	a) Cushions, b) storage solution, and c) LED lamp
10	Metal (from shop furniture)	Offcuts from punch holes and the punched full sheets	Designer waste sheets
11	Metal (machines and equipment)	Offcuts of oblong pieces and perforated sheets	Trolley
12	Cement-bonded wood wool (from building industry)	Baffle plates rejected due to imperfections in surface or broken corners	Acoustic wall art
13	Felt (from building industry)	Sheets from acoustic panels, rejected due to damages on surface	Organisers
14	Powder coating (from taps and fittings)	Collection of various colours of powder coating when cleaning pipes in between colours/types	Speckled powder coating
15	Steel (from kitchen tabletops)	Offcuts from sink and/or cooking plate	a) Shelf, and b) side table
16	PVC (from conveyor belts)	Offcuts of conveyor belts to adjust width	Lamp
17	Aluminium (from acoustic ceilings)	Smaller sheets with punch-holes, rejected because holes are not centred	Embossed acoustics panels
18	Marble / stone (from kitchen tabletops)	Offcuts from sink and/or cooking plate	a) Hooks, bowl, shelf and b) bedside table
19	Textile (from furniture industry)	Offcuts of textile pieces	Upholstery of designer chair

Table 2. Case descriptions including waste material, original application, and new product proposal

Results

Preserving material integrity level

Leveraging the integrity level of industrial waste to extend the material lifetime is at the core of designing with pre-consumer waste. The 19 cases are analysed according to the industrial waste's function, form, and material composition (hence, the integrity level) compared to which aspects are leveraged in the new product proposal. Some cases have more product solutions. Thus, 25 designs are assessed according to what the designer has preserved and elevated.

Leveraging on the original function/intention of the material is the most difficult, as the material has been rejected due to not living up to this intention. However, the leverage point poses the most significant potential in respecting and maintaining the already carried out processing. The form and material composition are automatically leveraged when leveraging on the function. The second-best option is to utilise the form of the material. Lastly, if it is not possible to leverage either function or form, the composition of the material will be utilised, thereby using the material properties in a new product. For the cases where the material does not come with a form (#6 concrete and #14 powder coating), they cannot be leveraged on a higher level than the material composition.

Eight designs have managed to leverage the function/intention of the waste materials in new products, whereas six cases leverage the form. The remaining 11 designs only leverage the material composition (Figure 4). An example of leveraging the function is case #17. Aluminium sheets from acoustic ceilings were rejected for flaws in the pattern. Through the reshape strategy, they have been embossed with a pattern that makes the flaws blend in, and the new product will again function as an acoustic ceiling.

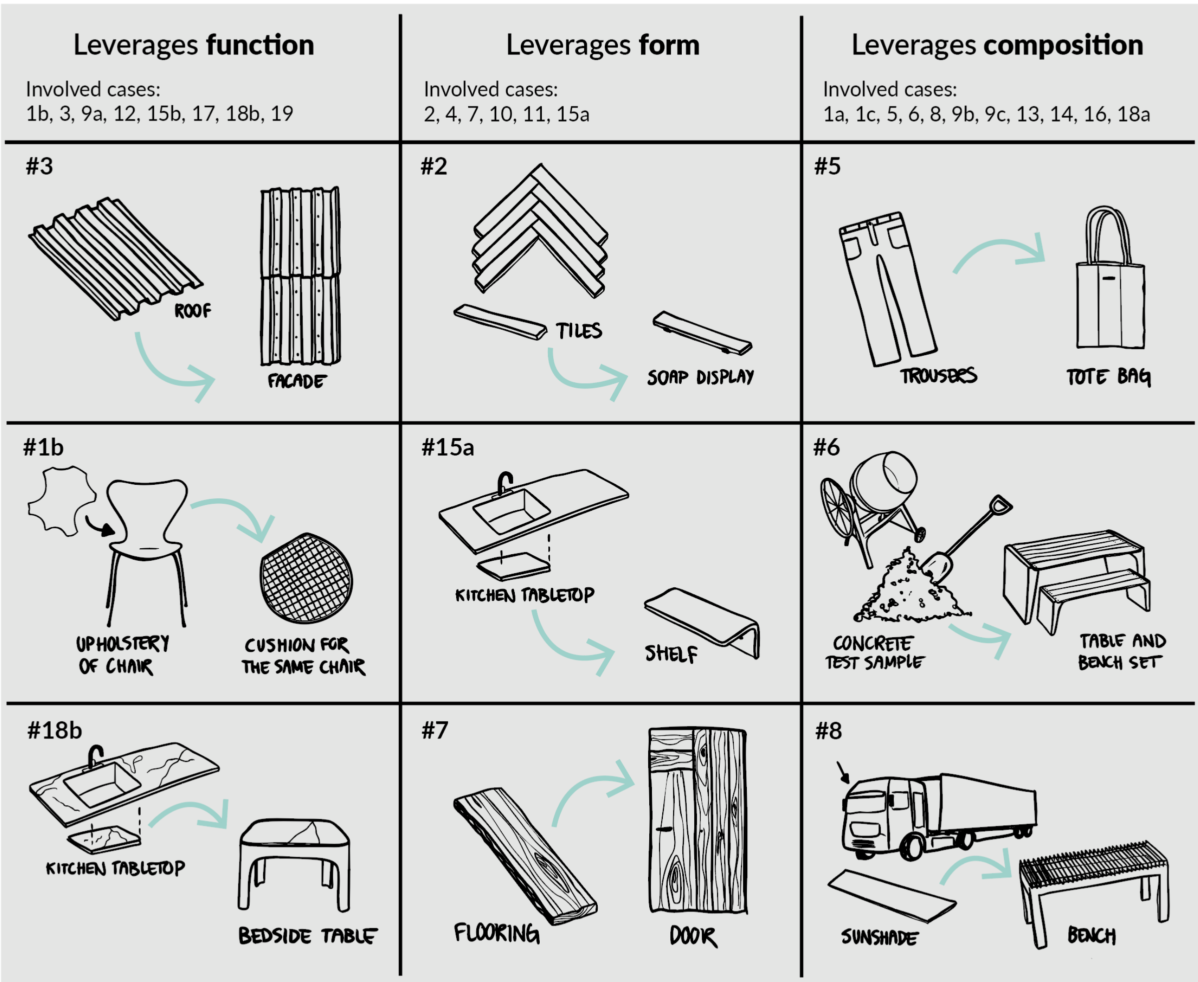

Figure 4. Mapping of cases according to leveraging on either function, form, or material composition. Nine case examples of the elevation of the material's integrity level in the new design

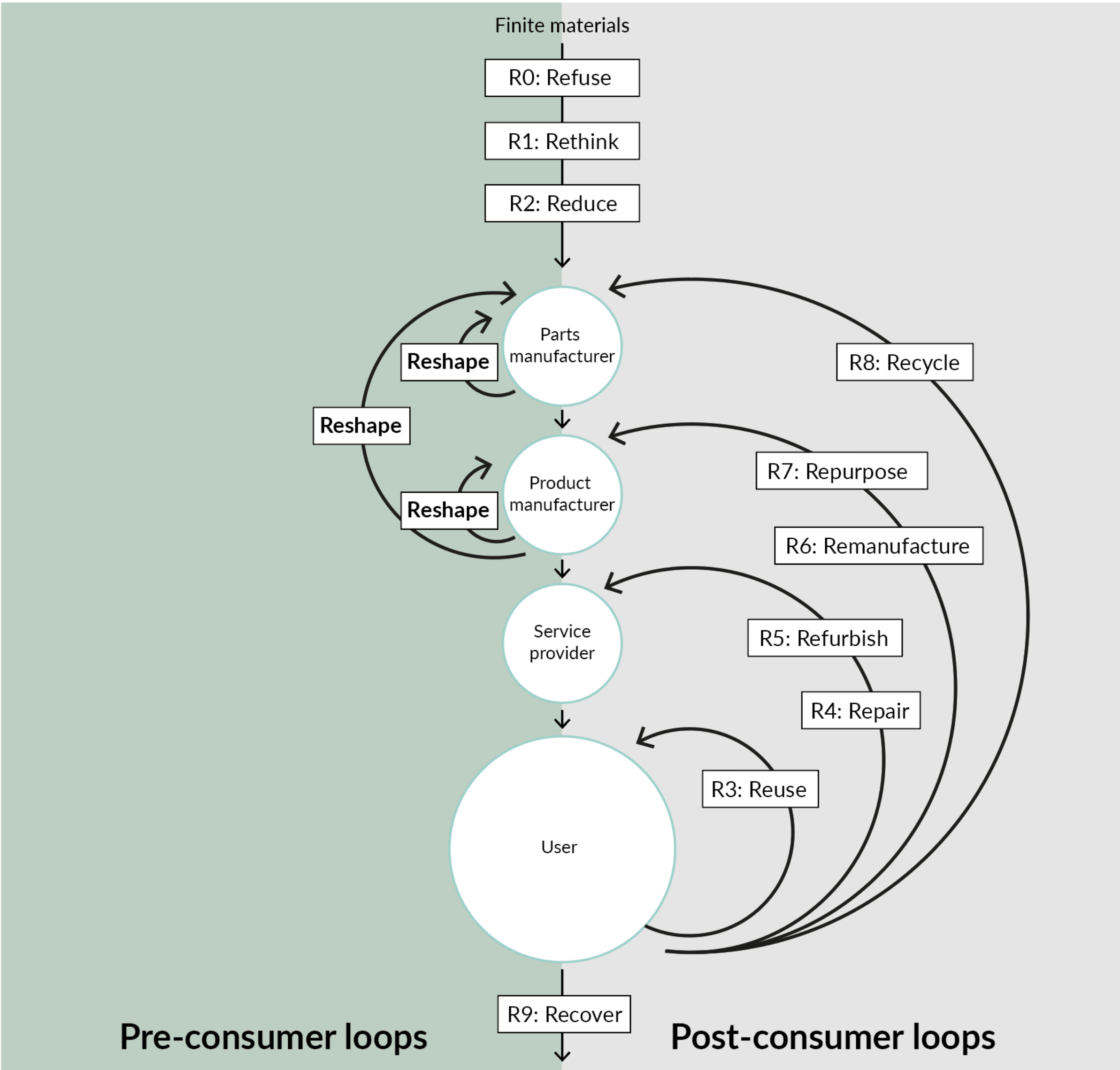

Figure 5. Development and division of the Butterfly diagram to pre-consumer and post-consumer loops with the introduction of the Reshape strategy. Adopted from (Ellen MacArthur Foundation, 2019; Potting et al., 2017)

The Reshape strategy

Through the analysis of the investigated cases, we empathise that circulation loops also occur at the pre-consumer stage (Figure 5), looping into the manufacturing industry without the necessity of going through the consumer and circulating through remanufacturing or recycling. The cases in this study focus on reshaping industrial waste into new products, an activity not covered by current strategies.

Thus, we suggest the introduction of the Reshape strategy that relates to the activity of leveraging industrial waste materials pre-consumer at the highest possible integrity level. We define the Reshape strategy as *Reshaping resources aiming to maintain the highest integrity level by leveraging function, form or material composition in new products*.

The strategy occurs pre-consumer in the development of new products (Table 3). We position it in existing frameworks underneath prevention/reduce and above the reuse strategy and the subsequent strategies that extend product lifetime and/or use of parts from a used product.

4R Framework (Kirchherr et al., 2017)	**9R Framework** (Potting et al., 2017)	
Reduce	**R0 Refuse** Make product redundant by abandoning its function or by offering the same function with radically different product.	Smarter product use and manu-facturing
	R1 Rethink Make product use more intensive (e.g. through sharing products, or by putting multi-functional products on the market).	
	R2 Reduce Increase efficiency in product manufacture or use by consuming fewer natural resources and materials.	
Reshape	**Reshape** Reshaping resources aiming to maintain the highest integrity level by leveraging function, form or material composition in new products	
Reuse	**R3 Reuse** Reuse by another consumer of discarded product which is still in good condition and fulfils its original function.	Extend lifespan of product and its parts
	R4 Repair Repair and maintenance of defective product so it can be used with its original function.	
	R5 Refurbish Restore an old product and bring it up to date.	
	R6 Remanufacture Use parts of discarded product in a new product with the same function.	
	R7 Repurpose Use discarded product or its parts in a new product with a different function.	
Recycle	**R8 Recycle** Process materials to obtain the same (high grade) or lower (low grade) quality.	Useful application of material
Recover	**R9 Recover** Incineration of materials with energy recovery.	

Table 3. The 4R and 9R Framework including the Reshape strategy, definitions from (Potting et al., 2017)

The strategy reshapes resources according to three leveraging levels, outlined with the position of the Reshape strategy in the waste hierarchy (Figure 6).

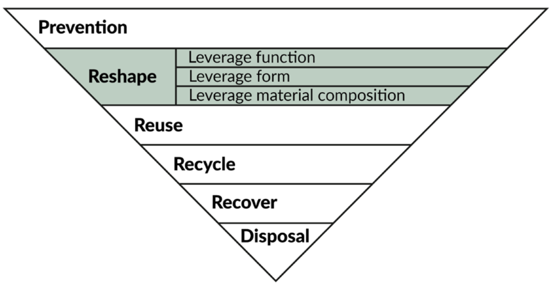

Figure 6. Reshape in the waste hierarchy

Concluding discussion

In the research on sustainable product design, circular R-strategies propose activities to increase the use of already circulating resources. However, the R-strategies are targeted at a post-consumer level; hence, industrial waste is overlooked. Through this study of analysing 19 case experiments with designing with waste materials, we introduce the Reshape strategy for preserving material integrity and extending the lifetime of materials in the circular economy concept. The strategy addresses waste in the manufacturing industry and loops back to manufacture new products. It supports designing inclusively with discarded materials by leveraging the function, and/or form, and/or composition of the material, thereby elevating the highest integrity level of the material starting point. The Reshape strategy proposes a design activity that preserves the integrity of the material by respecting and elevating the craftsmanship, time and energy that has been put into the processing of the materials.

With this research, we hope to contribute to the theoretical development of the circular economy concept by identifying and defining a circular strategy to support designers and practitioners in including industrial waste pre-consumer in new products.

There are many perspectives on the R-strategies. The Reshape strategy introduces a timely perspective, as it only comes into play at a pre-consumer stage, hereby challenging why and when this strategy should be chosen over others. Developing further aspects of the Reshape strategy would cement its position as a valuable strategy for reducing discarded materials that are downcycled or disposed of. Through our analyses, we have identified challenges with the manufacturing flows, e.g., whether the waste loops back into the same manufacturing chain and business or enters a new. It is considerable for waste utilisation, as it causes various opportunities and barriers according to business situations and involved actors, which calls for further research. Lastly, we propose examining how designers perform the activity of reshaping waste regarding e.g., technical, and aesthetic challenges.

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