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Defining alternative recovery strategies for reuse: An analysis of multiple case studies under the reuse umbrella

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Abstract: This study focuses on the role of the reuse recovery approach and its strategies in the circular economy through a product design lens. While the circular economy has been widely discussed, not all recovery strategies have been thoroughly investigated and understood alike. This research differentiates between reuse and other recovery strategies and defines three distinct opportunities under the 'reuse umbrella' – reuse, cascade and relink. For each opportunity, possible sub-opportunities are identified and elaborated. Through a multiple case study analysis, the sub-opportunities are elaborated with a "Design for X" approach into eight different strategies of reuse, including design for direct reuse, reconfiguration, material cascading, repurposing, component reuse, creative reuse, material reclamation and adaptive reuse. The research emphasises that the appropriateness of a reuse strategy depends on various aspects such as the context, users, industries, and material flows. Also, this study stresses the importance of reuse in promoting circular product development and consumption, providing valuable implications for businesses and designers.

Introduction

The concepts of reuse, cascading, recirculation, regeneration, reprocessing, repurposing, and renovation have deep roots in human history and have been a fundamental aspect of resource management for centuries. These practices have traditionally occurred on a local, informal level within households or communities, where resources were shared and conserved for generations among members (Sirkin et al., 1994). However, with the advent of wealth, particularly in developed economies, these traditional methods of resource management have been replaced by less sustainable practices (Cooper, 1994). But in recent years, there has been a renewed interest in these activities as they are seen as a viable solution to the environmental and societal issues caused by modern consumption practices (Wieser et al., 2018). This type of economy, based on circular economy (CE) and sufficiency, can foster a more efficient and sustainable society (Bocken et al., 2016). The aim of this research paper is to broaden the understanding of the concept of reuse from a design perspective and to present a novel approach to defining design strategies that maximise value reuse. Through the lens of the "Design for X" approach, we analyse the three strategies of reuse, cascading, and relinking to identify key strategies, components, and factors that contribute to successful initiatives (Sirkin et al., 1994). Our approach integrates the concepts of reuse with cascading and relinking to hierarchize strategies and emphasises the importance of reuse in the design process. By examining both implemented and conceptual case studies, we offer insights into potential future developments in this field and provide valuable information for designers and stakeholders interested in implementing reuse, cascading, and relinking strategies.

Materials and Methods

This study employed the methodology proposed by Yin (2011) to identify and analyse individual cases to gain comprehensive insights and understanding opportunities in design for reuse.

1. *Research questions*: How can designers approach the concept of designing for reuse, and what are the different design strategies that can be employed to support this objective?
2. *Research propositions*: A classification of the design for reuse strategies employed by designers, in terms of their approach, characteristics and applicability (in terms of different products, processes, and industries).
3. *Research unit(s) of analysis*: The various strategies that can be differentiated to formulate overarching approaches that can be adopted and replicated by designers, focusing on technical material cycles only.
4. *Logic linking the data to the propositions*: To understand reuse, a literature review was conducted (Stage 1), followed by case studies that were pattern-matched to definitions of reuse (Stage 2), and finally, each reuse strategy was described as a "design for X" strategy (Stage 3).
5. *Criteria for interpreting the findings*: The criteria used for this research are the following: (1) Aim of the DfX strategy; (2) Type (product, component, material), origin of the value and industries; (3) Intended reuse and functionality (same or different purpose); (4) Ownership of the product and responsibility for its use and maintenance during the usage; (5) Increase, no change, or a decrease in value (market value) compared to the previous life cycle; and (6) Reprocessing method for enabling reuse of the value and the entities accountable for performing it.

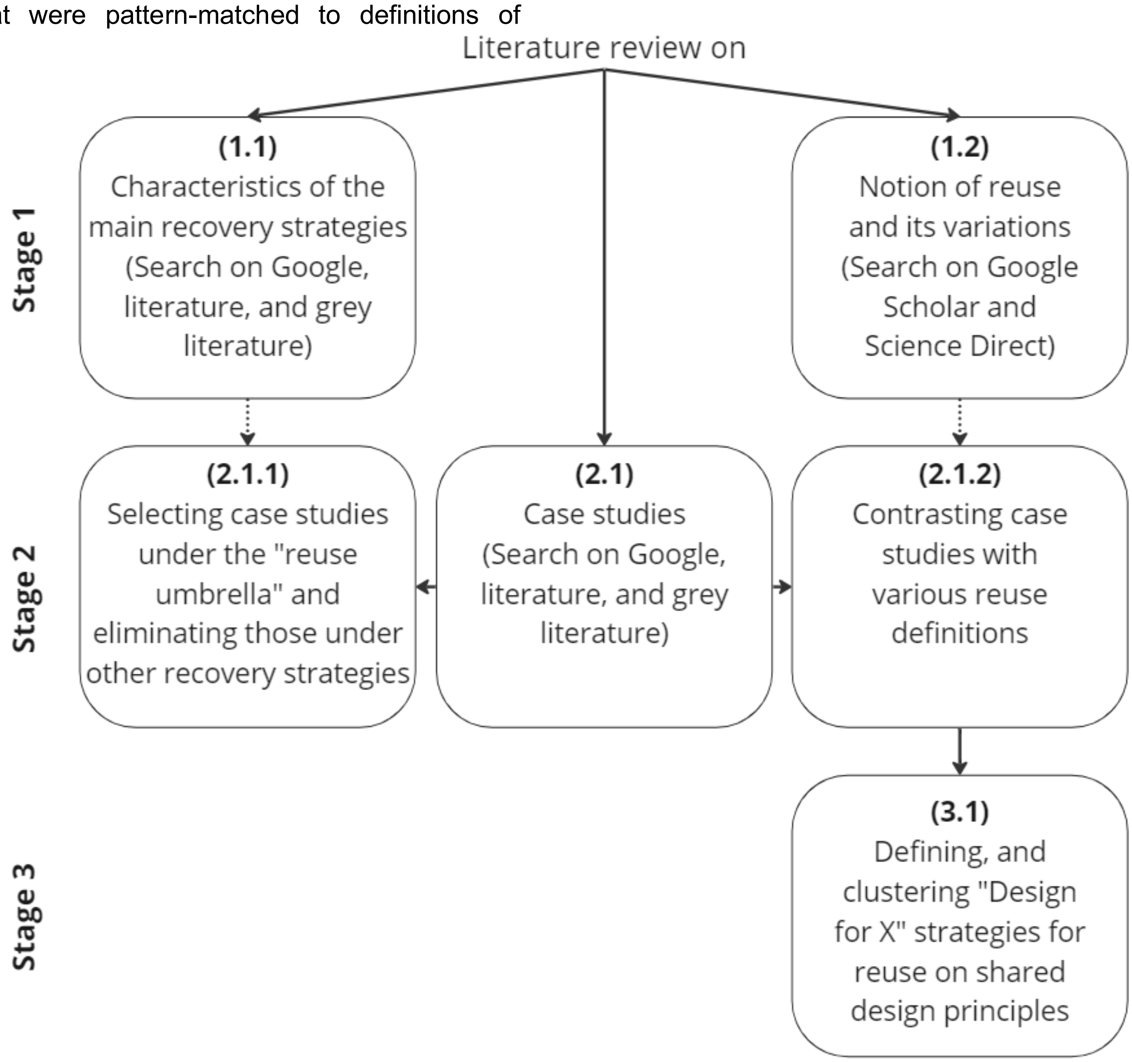

Figure 1. Stages of the multiple-case study analysis.

Results

Stage 1

In the initial stage, we conducted a comprehensive literature review on reuse in order to gain a holistic understanding of the subject. The literature reveals a common tendency to confuse the idea of reuse with alternative circular strategies, such as refurbishing or remanufacturing (Linton et al., 2005). This can result in a limited understanding of the potential impact of reuse, as well as the importance of prioritising the inner loop and retaining the highest value possible from a product (Wieser et al., 2018). The lack of clear differentiation between recovery strategies may impede progress towards more sufficiency and a CE (Gharfalkar et al., 2016; Reike et al., 2018). In order to fully leverage the benefits of reuse, it is crucial to distinguish it from other circular strategies and to highlight its unique characteristics and value. While there are a few attempts in the literature to define and categorise different approaches to reuse (Franconi et al., 2022), these efforts have been limited in scope and generally lack a comprehensive framework for analysis. The majority of authors who discuss reuse at a general level often rely on the definition provided by the EU (2008, Article 4(13)), which defines reuse as the reuse of a product "as is". However, some researchers who conduct a more in-depth analysis of the reuse phenomenon view it more broadly, encompassing components and materials (Keoleian et al., 1993; Beamon, 1999; Bavan et al., 2013; Chiu et al., 2011;). Table 1 combines the two approaches under the Reuse 'umbrella' and presents a comparative analysis of the main recovery strategies based on the following criteria: quality, aesthetics, intended reuse purpose, type of value (product, component, or material), design aim, reprocessing, and product market value.

	MAIN RECOVERY STRATEGIES					
CHARACTERISTICS	Long-lasting	Reuse umbrella		Refurbish	Remanufacture	Recycle
Quality	Original	"As is" and working condition	Reused it anyway possible	Like new/or almost new	Like new or better than new	Usually lower than the original
Aesthetics	Original	Original	High/low	Original	Original	Low
Intended reuse purpose	None	Same	Slightly same or different	Same	Same	Different
Type of value	Products	Products	Products, components, materials	Products, components	Products, components	Materials
Design aim	Longevity	Reuse	Maxime reuse	Restoration	Renovation	Maxime reuse
Reprocessing	Upgrading (expert or DIY)	Cleaning (expert or DIY)	Upgrading, Adaptation Retrofitting (expert or DIY)	Cleaning/Repair (expert repairing)	Disassembly/ Repair (expert repairing)	Recycling (expert)
Product market value	High	High	Low	High	High	Low

Table 1. Comparison of recovery strategies characteristics. Note that the table is based on a broad context, and characteristics may vary according to the specific case and context. An enlarged version of the image is provided in the appendix 1.

Very few attempts have been made to pinpoint what exactly constitutes reuse. Etienne (2015) identified 22 distinct overarching approaches for reusing activities. These approaches range from the use of formal reuse systems and the implementation of product evaluation and repair facilities to more informal and community-based approaches such as the sharing economy and water reuse. Aguirre, (2010) focused more on the design aspect of repurposing. She suggests three types of repurposing initiatives: (1) Planned repurposing, (2) Coached repurposing/suggestions, and (3) Open-ended repurposing. In their study, Sihvonen et al. (2015) proposed a comprehensive classification of reuse strategies, which was primarily categorised into six groups: (1) Resale or direct reuse, (2) Repurpose, (3) Repair, (4) Refurbish, (5) Remanufacture, and (6) Resynthesize. The authors sought to provide a systematic framework for evaluating and implementing various forms of ReX for aggregating end-of-life strategies. Sirkin and ten Houten (1994) directed their attention towards the economic and practical dimensions of reuse. They were the first to introduce the notion of cascading and relinking as a means of distinguishing whether the product gains or loses worth during the process of reuse. Their work enabled the categorization of 'reuse umbrella' into three distinct types, namely Reuse (value remains unchanged), relinking (value increases), and cascading (value decreases). These categorisations were subsequently used to group and analyse various reuse concepts from existing literature. The selection and organisation of terms with equivalent meanings are summarised in Table 2.

	Categorisation of reuse based on value	Terminology of reuse selected for this study	Alternative terminology used in literature
Reuse umbrella	Reuse (value remain unchanged)	Direct Reuse	Resale or direct reuse (Sihvonen et al.), Reuse (Keoleian, et al.); Conventional Reuse, Reusable, and Second-Hand products (Etienne); Reuse (Wilts et al., 2018)
		Reconfiguration	Reconfiguration (Sibanda et al.); Reusing structural components for multiple service cycles (Brütting et al.)
	Cascading (value decrease)	Repurposing	Planned repurposing and coached repurposing/suggestions (Aguirre, 2010);
		Component Reuse	Reuse (Keoleian, et al.). Salvage (Etienne), Upgrading (Wilts et al., 2018).
		Material cascading	Material cascading (Sirkin et al.), Reclamation (Etienne).
		Creative reuse	Resynthesize (Sihvonen et al.); Open-ended repurposing (Aguirre, 2010); Creative Reuse (Etienne); Individual Upcycling (Sung et al); Individual upcycling (Sung et al.)
	Relinking (value increase)	Material Reclamation	Reformulation (Keoleian, et al.); Deconstruction, Reclamation (Etienne).
		Adaptive Reuse	Repurpose (Sihvonen et al.); Adaptive Reuse (Etienne)

Table 2. Taxonomy, semantics, and clustering of terms based on literature analysis. An enlarged version of the image is provided in the appendix 2.

Stage 2

In the second phase of our study, we conducted a case study investigation using various research engines: Google, Google Scholar, JSTOR and ScienceDirect. The resultant data was compared against Table 1 as a first step. If a particular case study fell under the 'Reuse umbrella' category, it was further categorised in accordance with Table 2. Following this selection process, we have identified a cohort of 40 case studies.

Stage 3

In the final phase of our study, we used the Design for X (DfX) approach to articulate all the strategies falling under the umbrella of reuse. To this end, we first created a generic description of the case studies, which were organised according to different categorizations. DfX is a systematic approach that seeks to optimise the design of products or processes by considering various factors or "X's." In our study, we used DfX to explore how different reuse strategies can be applied in various contexts. Specifically, we employed DfX to generalise and articulate the different reuse strategies based on the definitions and case studies that we identified. This involved analysing each strategy in terms of how it could be optimised for different factors or X's, such as repairing components or incorporating modularity. Furthermore, we applied five distinct criteria, as detailed in our methodology, to fully articulate each reuse strategy.

Design for Reuse (DfR)

This strategy focuses on designing products that can be reused "as is". There are two strategies that can be used within DfR that are:

1. Design for Direct Reuse (DfDR)

DfDR aims to create products that can be easily and directly reused "as is". It comprises two groups of products: (1) reusable containers, packaging, medical or industrial equipment, and (2) second-hand products such as clothing and vehicles. In group (1), designers focus on creating aesthetically simple products with durable, easy-to-clean, and high-quality materials that are safe for reuse. Products in this group are typically borrowed, rented or require a small deposit that is refunded upon purchase of the next product (Fig. 2). Group (2) includes high-quality, long-lasting products that boast extended service lifetimes but are not necessarily designed with reusability as a goal (Fig. 3). Users in this group exchange products with one another, by themselves or through intermediaries (e.g. resale platforms). Both groups consider reprocessing as cleaning for immediate reuse.

Figure 2. Refill water dispenser jar. © Pixful
Figure 3. Worn Wear program. © Patagonia.

2. Design for Reconfiguration (DfRF)

DfRF aims to design products with modular, adaptable, and reconfigurable components that can be easily disassembled and reassembled to create new products or upgrade existing ones. This strategy incorporates modular design, universal connections, snap-fit mechanisms, reconfiguration equipment, and durable materials, as well as instructions for disassembly and reassembly, to create adaptable and versatile products. DfRF products may require extensive reprocessing to be able to be reused again and adapted to a new function. Examples are scaffolding, stage structures, furniture with specialised splicing (such as Comma by Vitra), or specialised materials reconfigured with reconfiguration equipment such as Transitory Yarn.


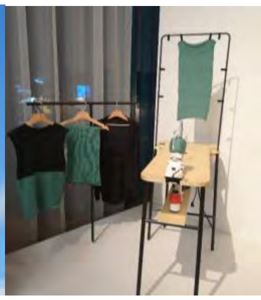

Figure 4. Scaffolding. © Pxfuel
Figure 5. Transitory Yarn. © Alexandra Fruhstorfer.

DESIGN FOR CASCADING (DfC)
DfC is the practice of designing products that are able to increase value after reuse. DfX strategies include:

1. Design for Material Cascading (DfMC)

DfMC aims at facilitating the reuse of production waste, as well as post-consumer waste materials composed of multiple components that are difficult to recycle. These materials are often reused as filling or support materials for other products, as traditional recycling methods are typically not feasible. When products or materials are reused under this strategy, they typically undergo a change in function and a significant decrease in value, with significant or moderate reprocessing required for reuse (e.g. non-recycling mechanical processes like shredding or pressing). Examples are carpet padding, textiles as reinforcements of building materials, temperature insulation materials and padding and stuffing materials.


Figure 6. Carpet padding. © Flooring Clarity.

Figure 7. Insulation made of mineral wool, glass, and glass slabs. © Knauf Insulation.

2. Design for Repurposing (DfRP)

DfRP aims to enable the efficient reuse of resources for subsequent purposes. It focuses on creating value by enabling functional changes in each step of the reuse process, while typically resulting in similar or lower market value compared to the previous life cycle. Reprocessing is minimal or not required, with ownership remaining with the user who is responsible for its use and maintenance. Examples are mainly packaging as shown in Fig. 8 and 9.


Figure 8. Nutella Simpson Glass Tumblers. © The Hawkins Treasures.
Figure 9. HangerPak. © Steve Haslip.

3. Design for Component Reuse (DfCR)

Technically, DfCR aspires to create components that can be simply disassembled and reused "as is" in other products when the entire product cannot be resold, repaired, or recycled. However, currently, this strategy is primarily utilised for goods that were not initially designed with DfCR principles in mind. DfCR is particularly applicable to products that are susceptible to wear, obsolescence, or damage (such as cars involved in accidents). Designers should consider end-of-life scenarios, use modular design and standardisation of components, and collaborate with recovery facilities to facilitate salvaging reusable parts. Usually, reprocessing requires much manual labour such as disassembling and cleaning components before reusing them in a different product. The reuse of the different components can require creative solutions like Fig.10. Other examples include cars (Fig. 11), computers and workwear components.


Figure 10. Recraft line. © Patagonia.
Figure 11. Reusable vehicle parts. © Alessio Franconi.

4. Design for Creative Reuse (DfCR)

DfCR aims to create new products from dismissed materials or products using craft, manufacturing techniques (such as 3D printing), and artistic approaches, resulting in products with unique aesthetic qualities that extend the lifespan of the original materials or products and differ substantially from the initial lifecycle. DfCR involves two sub-strategies:

Design for Individual Upcycling (DfIU) and Design for Professional Creative Reuse (DfPCR), which use discarded products, components, and materials to create new products with different market values. The process of DfCR involves a range of activities, including material reworking, heating, and the incorporation of different components and products. DfCR falls under both DfC and DfRL because, depending on who employs this strategy, i.e., a professional or a DIY enthusiast, the reused product might either gain or lose value. Diverse examples of DfIU can range from small, disposable objects to household furniture, as depicted in Figures 12 and 13. Similarly, Figure 14 and 15 illustrate the wide applicability of DfPCR.


Figure 12. Nutella jars repurposed as vases: a DfIU case. © Nutella.com
Figure 13. Wine bottles repurposed as tumblers: a DfIU case. © Wasabottle on Etsy.

DESIGN FOR RELINKING (DfRL)
DfRL is the process of designing resources in a manner that enables their reuse and increases their value in subsequent cycles. DfX strategies within the DfRL include:

1. Design for Creative Reuse (DfCR)

As previously described.


Figure 14. Cubicle 2: a DfPCR case. © Formafantasma
Figure 15. 3D printed Vases Collection: a DfPCR case. © Libero Rutilo.

2. Design for Material Reclamation (DfMR)

DfMR aims to recover and reuse waste materials without recycling and uses them "as-is" to build new goods. DfMR involves identifying sources of abundant waste materials (non-recyclable or with high economic value potential), implementing a scalable solution for those sources, and designing tailor-made solutions to reprocess and reuse these materials. The goal is to generate products that have a higher value and a different purpose than the original product. Figures 16 and 17 illustrate a few applications of this strategy.


Figure 16. Messenger bag. © Freitag
Figure 17. Small Post Bag. © Elvis & Kresse.

3. Design for Adaptive Reuse (DfAR)

DfAR aims to maximise conservation and minimum transformation characteristic of a product by retrofitting or updating with adaptable components. It focuses on creating value by enabling alternative features that the product did not initially have and in doing so prolongs the life of the product. To achieve this, designers focus on creating retrofitting products that are modular and flexible, allowing them to be easily adapted, assembled and integrated to existing products. Figures 18 and 19 illustrate a few applications of this strategy.


Figure 18. Jar Tops. © Jorre van Ast.
Figure 19. Nutella Clock. © Alessi.

Discussions and conclusions

This paper aims to provide clarity on the implementation of design strategies for resource reuse by answering the question, "How can designers approach the concept of designing for reuse, and what are the different design strategies that can be employed to support this objective?" A classification system based on three main approaches - design for reuse, cascading, and uplinking - is used to define eight sub-strategies that provide a comprehensive understanding of reuse design opportunities. Effective implementation of these strategies can have a substantial impact on the savings of material, labour, energy, and capital required for the product, and externalities such as greenhouse gas emissions, water usage, and toxicity. However, successful implementation is contingent upon a variety of factors, including context, users, industries, and material flows. To maximise adoption of reuse strategies, designers need to tailor their designs according to these factors. Future research directions include proving the quantitative economic and environmental benefits of implementing the different strategies for businesses, analysing the different design strategies in depth, and exploring the impact of the narrow definition of reuse used in official reports by the UK and EU governments.

Acknowledgments

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Appendix 1

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Design aim	Longevity	Reuse	Maxime reuse	Restoration	Renovation	Maxime reuse
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Product market value	High	High	Low	High	High	Low

Appendix 2

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		Material Reclamation	Reformulation (Keoleian, et al.); Deconstruction, Reclamation (Etienne);
		Adaptive Reuse	Repurpose (Sihvonen et al.); Adaptive Reuse (Etienne)