# Design for High Added-Value End-of-Life Strategies

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**Abstract** Sustainable manufacturing is a rising issue. Ensuring both consumer satisfaction and minimal environmental impact is very challenging. In that whole process, it is customary to say that the design stage determines 80 % of the future environmental impact. One way to contain this impact at an acceptable level is to manage the products' end-of-life from the design activities. This chapter points out product reuse strategies—i.e. *direct reuse and remanufacturing*—aiming at conserving the added-value of used products as much as possible into new products. The first contribution attempts to provide a state-of-the-art of design for these high added-value end-of-life strategies. Direct reuse and remanufacturing are thus analysed and the principal design guidelines are furthermore given, classified according to three dimensions: product, process and business model. This chapter then contributes to enlarging the spectrum of reuse strategies, presenting an innovative end-of-life strategy: repurposing. It consists of reusing products in other applications after transformations. The main challenges of such a strategy will be discussed.

**Keywords** Design for X · End-of-life strategy

## 1 Introduction

There is a need to improve the environmental orientation of products and the management of their end-of-life (EoL) represents one way of achieving this. Many studies argue that it could be initiated from different actors: customers, pushing for greener products; companies, willing to reduce the environmental footprint of their products as much as increasing their revenues; or regulation, favouring

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low-impact-products and obligating producers to handle their end of life processes, beginning with the design phase (Global Reporting Initiative 2013; Goodall et al. 2014).

An end-of-life strategy refers to the manner in which one manages the product right after its user has discarded it. The focus today is on end-of-life strategies that maximise the value of the products, so-called reuse strategies. These strategies have key characteristics that must guide designers to facilitate their initial setup. This chapter tries first of all to make these strategies clear as well as outline what the drivers are for the most adapted designs. An exploration follows, of how the main end-of-life strategies maximise the value of products, along with how to support product designers in their willingness to pursue these maximizing-value strategies.

These end-of-life strategies and their consequences on the design of products are now well-known and shared among companies: the product characteristics, its performances and the recovering process are described in literature. Nevertheless, the discussion is open to proposing new strategies that retain more and more added value of used products for the purpose of ultimately manufacturing innovative products. Repurposing, meaning that end-of-life products can be revamped into different applications than the former ones to prolong their lifetime, needs now to be understood, modelled and analysed in pursuit of guaranteeing its implementation and its potential value.

Following this introduction, the chapter describes the product end-of-life strategies in Sect. 2, before focusing on high added-value strategies, and reuse strategies, in Sect. 3. They will be described in terms of product, process and business model characteristics and an overview of the main guidelines for assisting the product design work will be summarized. Section 4 paves the way for the repurposing strategy to be presented and discussed.

## 2 High Added-Value End-of-Life Strategies

The need to define a product end-of-life strategy takes place when the product is considered as a 'waste' (European Commission 2008). The European Commission (2008) defines *waste* as: "any substance or object which the holder discards or intends or is required to discard." Depending on its type, characteristics and working conditions, the discarded product may follow one or another strategy. ISO proposes a classification of end-of-life strategies though the standard 14062 (ISO 2002), which has been ranked depending on potential environmental gains: (a) prevention, (b) reuse, (c) recycling, (d) energy recovery and (e) disposal; (European Commission 2008). In this chapter, the focus is set on strategies which aim at maintaining as much added-value in products as possible.

First of all, energy recovery and landfilling do not represent sustainable strategies since they do not recover any element of the products: both added value and material are destroyed. These strategies will be grouped under the "waste" label in the chapter (see 1 in Fig. 1). Recycling (see 2 on Fig. 1) consists of recovering

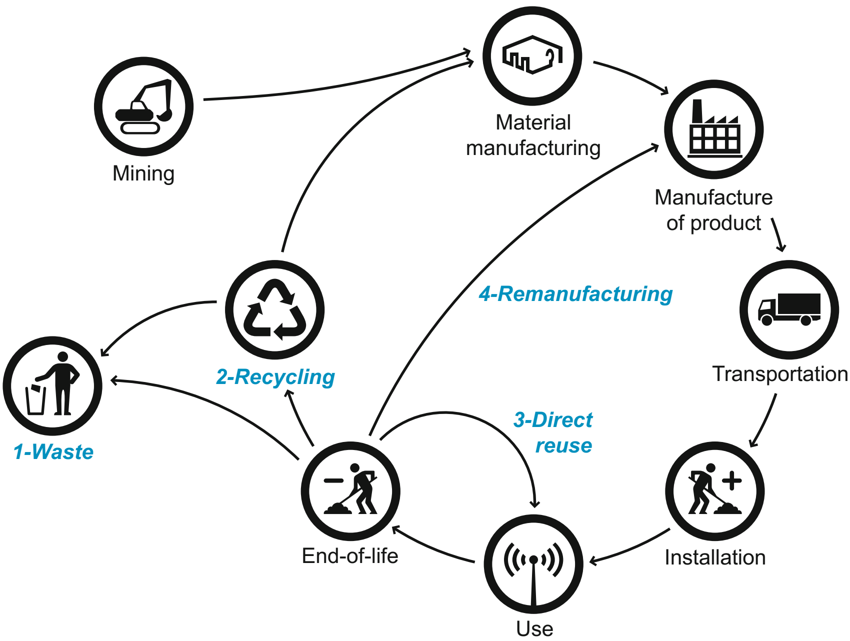


**Fig. 1** Product lifecycle and the 4 main end-of-life strategies (adapted from Zhang 2014)

materials from the discarded products in order to avoid new raw material extraction and, in so doing, limit the environmental impact and supply issues. The recycling strategy destroys the added-value of the product and instead only recovers materials. The strategies that recover material and retain the product's added-value are called reuse strategies. It can be split in two distinct sub-strategies: direct reuse and remanufacturing. Direct reuse (see 3 on Fig. 1) is a process where the quality of the product and the market conditions allow for continued use of the same product by another customer. The remanufacturing strategy (see 4 on Fig. 1) concerns products that have to go through a new manufacturing process before being put back on the market. Indeed, direct reuse and remanufacturing both aimed at providing as-new products with at least the same guaranties and performances as a new product and for the same application. Finally, prevention mainly consists of avoiding the impact before the end of the product life, by minimizing wastes.

The paper focuses on end-of-life strategies that conserve added-value of products, meaning the materials after manufacturing transformation. These strategies are called "reuse strategies." The "quantity" of added-value retained, and the corollary "quantity" of transformation needed to recover the added-value missing, characterize the process of remanufacturing of the product from "high added-value retained—light remanufacturing process" (direct reuse strategy) to "less but real added-value kept—standard remanufacturing process" (remanufacturing strategy).

## 3 Design for Direct Reuse and Remanufacturing

The focus of this section is on reuse strategies happening right after the End-of-Use (EoU) of products. A distinction is made between Design for direct Reuse (DfdR) and Design for Remanufacturing (DfRem). Definitions, explanation and design guidelines are pointed out.

### *3.1 Definitions and Main Characteristics*

The direct reuse strategy may be defined as: “any operation by which products or components that are not waste are used again for the same purpose for which they were conceived” (European Commission 2008). Gelbmann and Hammerl (2015) state that the performances of the directly reused product must be as good as a new one to achieve the same function while Arnette et al. (2014) assert that products have to be “good enough” to fulfil the following use. In any case, products need to be in sufficient working condition to be reused directly. Products which are reused directly are often however considered second-hand products and their components used to repair other products (Go et al. 2015) instead of becoming a product in and of themselves. This implies new products manufacturing instead of potential reuse of products. In terms of the manufacturing process, the direct reuse strategy involves already-used products’ collection from the waste stream, cleaning, sorting and testing of products (Gelbmann and Hammerl 2015; Go et al. 2015). These steps make it possible to solve potential problems and ensure their well-functionality so that they can be reused directly in similar applications (Pigosso et al. 2010; Arnette et al. 2014; Gelbmann and Hammerl 2015). The remaining unsettling factor about the definition of direct reused products concerns its legal status after the first use. Some authors (Gelbmann and Hammerl 2015) insist on considering them as wastes since the European Commission (2008) no longer does this. In the latter case, the product shall ceased to be defined as such upon following different steps to be reintroduced onto the market (European Commission 2008).

The remanufacturing strategy has largely been studied over the past decades. Lund (1984) gave the first definition of remanufacturing and stated it to be: “an industrial process in which worn-out products are restored to like-new condition.” This definition has been adapted by the European Commission (2015), which describes remanufacturing as “a series of manufacturing steps acting on an end-of-life part or product in order to return it to like-new or better performance, with corresponding warranty.” The most important matter to appreciate here is that manufacturing processes will be needed in order to bring products back to their original state or to a better state. In other words, the remanufacturing process attempts to recover as much added-value from the original manufacture as possible (Zwolinski et al. 2006; Gray and Charter 2008). The remanufacturing process may be slightly more complex than direct reuse. The starting point for remanufacturers is to obtain from the user, the collected-used products and return them to their factories. Sundin and Bras (2005) detail seven generic process steps for the remanufacturing business: inspection, storage, cleaning, disassembly, reassembly, repair and testing. These steps—in part or in full—are found in any remanufacturing activity whatever its sector of activity.

In both direct reuse and remanufacturing strategies, the objective is the same: deliver to the market a product that is similar to the initial one and built from the initial materials. They both ensure reuse objectives, while the main difference stems from the quantity of operations needed to make the product reusable again. If the process needed to rebuild the product is mainly a cleaning process, it is considered as direct reuse. Otherwise, if the process calls for machining and more complex operations, it constitutes a remanufacturing strategy. Both strategies aim at lowering our environmental pressure. Among the different end-of-life strategies, direct reuse is said to have the best environmental and economic advantages (European Commission 2008; Arnette et al. 2014; Go et al. 2015; Gelbmann and Hammerl 2015), while remanufacturing is second (Sundin and Bras 2005; Hatcher et al. 2011; Go et al. 2015). Gray and Charter (2008) quote that the remanufacturing strategy would require 85 % less energy than manufacturing. Direct reuse should not require new high energy consuming transformations. Furthermore, they would both preserve resources, as they could be seen as "a new product avoided." Hatcher et al. (2011) furthermore add that it could be "a combination of new and reused parts." The main drawback of both strategies lies in the efficiency-in-use of the product when reused. Indeed, direct reused and remanufactured products—even if they are as-good-as-new—may be less efficient than brand-new ones due to technological evolution.

## *3.2 Design for Reuse*

In order to evaluate the different reuse strategies, i.e. direct reuse and remanufacturing—it is important to define a common framework of analysis in line with the customary design processes.

### 3.2.1 Different Reuse Strategies Under a Single Framework

When designing for sustainability purposes or for the environment, it is crucial to include all the different lifecycle steps, from cradle to grave—i.e. from raw material extraction to end-of-life stages, including manufacturing and use phases (Crul and Diehl 2009). From that point, a classic description of such strategies would distinguish products characteristics from manufacturing processes, or else design from production. This may come from bygone days when design office and production planning department were two separate entities. Nowadays, with integrated design, external parameters have to be considered all along the lifecycle of the product

(Brissaud and Tichkiewitch 2000). This leads to a better organisation of the overall offer, whether it be in terms of stakeholders' relationships, value creation, value chain of the offer, or any surrounding elements. All these elements are then gathered under the business model label. A parallel has already been made in the remanufacturing literature, where Gray and Charter (2008) pinpointed these three dimensions (called spheres) and distinguished Product characteristics from manufacturing Processes and Business Model features (P.P.BM. spheres). Indeed, Sundin and Bras (2005) and Zwolinski et al. (2006) detailed product characteristics and process activities considering external factors.

The P.P.BM. spheres are considered in this paper for the purpose of structuring the design guidelines. These guidelines help designers to define product and process parameters in line with the strategy of the company. The *product* area covers the product itself and its components. Their main characteristics are defined in order to distinguish products from different EoL strategies. The *process* concerns the different steps put in place in order to deliver the products and assign their respective characteristics. The Business Model defines the global strategy for delivering the product and its organisation. Each of these three spheres entails specific characteristics defined from literature in Bauer et al. (2016) and recalled in Tables 1, 2 and 3.

### 3.2.2 How to Design These Kinds of Products?

Design processes have largely been studied in the literature (Tomiyama et al. 2009). Design tools and methods have been well-known for years and many improvements have already been made, especially with integrated design (Brissaud and Tichkiewitch 2000). Indeed, designing a product implies the interaction from multiple areas of expertise in a single company. In that process, gathering the different actors from the early stages would facilitate the integration of the different constraints, whether they were linked to the product, the process, or the business model. From that point, the design process follows different steps to progress from the product idea to the product retirement (see Fig. 2).

Although they follow a reuse strategy at their end of use, to-be-reused products need to be considered like any other manufactured ones in the first place, so that the design phases between the two would not change much (Gray and Charter 2008). Despite that, the key issue for to-be-reused products lies in integrating the required parameters that are designed to ensure the end-of-life strategy. To be set up efficiently, they have to be integrated from the early design stages (Gray and Charter 2008). Hence, reuse can be seen as a classic integrated design, with specific attention to end-of-life parameters.

**Table 1** Guidelines: process sphere (classified by characteristics)

| Characteristics | Guidelines for reuse strategies | Guidelines for Remanufacturing strategy only |
|---|---|---|
| **Stable process** | Standardise and use common tools<br>Reduce the diversity of components<br>Reduce the variation in cores | |
| **Inspection & Sorting** | Minimise inspection time<br>Mark inspection points clearly<br>Minimise the number of different materials<br>Use standard components | |
| **Cleaning** | Avoid components that can be damaged during cleaning process<br>Minimise geometric features harming cleaning process<br>Identify components requiring similar cleaning processes | Facilitate access to the cleaning process<br>Ensure marking on product can survive cleaning process |
| **Dis/Re-assembly** | Avoid permanent fasteners that require destructive removal<br>Increase corrosion resistance of fasteners<br>Reduce the total number of fasteners<br>Reduce the number of press-fits<br>Standardise and use common fasteners (type and size) | Minimise disassembly and reassemblyt ime<br>Arrange parts and components to facilitate assembly, especially the ones that are easily prone to damage<br>Use assembly techniques that allow easy access to inspection points<br>Use assembly techniques that allow upgrade<br>Use assembly techniques that will withstand overall remanufacturing processes but that will not allow for damage to components that have the potential to be reused/ remanufactured<br>Use robust materials to ensure assembly operations |
| **Storage** | Ensure no damage during storage | |
| **Remanufacturing** | | Standardise and use common processes |
| **Testing** | Minimise thenumber of tests<br>Reduce test complexity<br>Standardise tests<br>Reduce the number of tests at the level required<br>Facilitate tests of components<br>Provide testing documentation | |

## 3.3 *Main Guidelines for Design for Direct Reuse and Remanufacturing*

The reuse literature is already overflowing with design guidelines for facilitating the adoption of direct reuse and remanufacturing strategies (Ijomah 2009; Arnette et al. 2014; Go et al. 2015). In the same manner, three spheres have been proposed (Bauer et al. 2016) to characterise end-of-life strategies. The categorisation of

**Table 2** Guidelines: product sphere (classified by characteristics)

| Characteristics | Guidelines for reuse strategies | Guidelines for Remanufacturing strategy only |
|---|---|---|
| **Reliable product** | Select reliable materials<br>Select reliable components | |
| **Durable product** | Select durable materials<br>Select durable and robust components<br>Prevent core damage<br>Prevent part and surfaces against external environment<br>Avoid components that can be damaged during cleaning process | Avoid components that can be damaged during inspection process<br>Avoid components that can be damaged during disassembly process<br>Avoid components that can be damaged during refurbishment process |
| **Functional prob.** | | |
| **High initial cost** | | |
| **Efficient product** | | |
| **Modularity / Upgradability** | | Standardise and use common materials, components and fasteners<br>Use modular parts and components thus reducing complexity of disassembly because types of assembly techniques are reduced<br>Structure the product and parts to facilitate ease of upgrade |
| **Physical elements** | | Avoid permanent fasteners that require destructive removal<br>Increase corrosion resistance of fasteners<br>Standardise and use common fasteners (type and size)<br>Reduce the total number of parts, components, fasteners, press-fits and joints<br>Specify materials and forms appropriate for repetitive manufacturing |
| **Stable technology** | Standardise and use common materials, components and fasteners<br>Standardise and use common interfaces<br>Design reusable parts and components<br>Facilitate access to components<br>Facilitate switch of damaged components | |
| **Documentation** | Provide readable labels, text, and barcodes that do not wear off during the product's service life<br>Provide good documentation of specifications, clear installation manuals and testing documentation<br>Provide clear information about product, parts, components and materials<br>Set up sacrificial parts to give an indication of the components' state of life | |

**Table 3** Guidelines: business model sphere (classified by characteristics)

| Characteristics | Guidelines for reuse strategies | Guidelines for Remanufacturing strategy only |
|---|---|---|
| **Ease of reuse** | Verify the market acceptance of the offer<br>Determine the internal skills needed | Reduce the rejection of remanufactured products |
| **Ease of supply** | Embed mechanisms into the product to ensure the return of cores<br>Facilitate collection of core parts<br>Facilitate Reverse logistics | |
| **Economic motivation** | | |
| **User profile** | | |
| **Remanufacturing reason** | | |
| **Partnership** | | |
| **Legislation** | | |
| **Environmental gains** | Avoid toxic materials<br>Determine the cleaner production anduse | |


**Fig. 2** Common design stages in product development

design guidelines according to one of the P.P.BM. sphere and then to the closest characteristic it would be linked to, is what is proposed here. Designers are therein provided with the guidance necessary for identifying which rule would lead to which characteristic. Some characteristics are created or renamed when the initial ones are not relevant enough for a design activity.

The two specific reuse strategies—direct reuse and remanufacturing, their characteristics and design guidelines are classified in Tables 1, 2 and 3. Guidelines dedicated to both direct reuse and remanufacturing were grouped together in one column labelled '*Guidelines for reuse strategies*', while the ones specific to remanufacturing were separated in the right-hand side column. Table 1 thus clusters characteristics and guidelines addressing the process Table 2 then gathers the different characteristics and guidelines connected to the product. The principal elements are related with direct product characteristics, such as durability and reliability, and physical elements facilitating the strategy—e.g. fasteners, parts…. The main process steps are recalled and specific guidance is provided. Finally, Table 3 covers the business model characteristics and guidelines. It is mainly a matter of organisation and reverse logistics.

Two points immediately stand out for careful discussion. First, it appears that some characteristics do not have any concomitant guideline. The reasons are that none of them has been identified in literature or due to the fact that the guideline was closer to another characteristic. The knowledge corpus will be increased with literature progress. The second point concerns the repartition of the guidelines. It appeared that all the guidelines related to direct reuse strategy were included in the remanufacturing strategy (grouped together in the column labelled '*Guidelines for reuse strategies*'). Nevertheless, some have only been identified in DfRem literature. This seems logical, however, as, the major difference between both is that remanufacturing implies more remanufacturing before the product could go back to the market. This is noticeable in the Tables 1, 2 and 3: all specific remanufacturing guidelines are directly or indirectly related to the remanufacturing process steps.

## *3.4 Discussion*

The characteristics have been highlighted and organised according to the P.P.BM. spheres. Design guidelines from literature were then linked to the most relevant reuse characteristic. If everybody agrees on the end goal of maintaining a high level circular economy, the applications are not as numerous as expected (Gelbmann and Hammerl 2015). Reused products may not yet be well-accepted on the market (Arnette et al. 2014), nor are design guidelines practical enough for each particular product.

The primary difficulties in implementing the reuse strategies remain. One key parameter concerns the reverse logistic chain, hitherto not well addressed as it mainly depends on company decision-making (Hatcher et al. 2011; Go et al. 2015). Indeed, the crucial step is to retrieve already-used products in pursuit of ensuring direct reuse or remanufacturing. This issue has to be defined from the design stages (Go et al. 2015). That is, the company needs to know where the retired products will be, how to get them back, and how to set up the logistics for bringing them back to the company or to another defined point (Gelbmann and Hammerl 2015; Go et al. 2015). These steps may rely on partnerships (Gelbmann and Hammerl 2015). The second point is related to the difficulty in putting the strategies in place *a posteriori*, after the products have been designed and *lived* (Hatcher et al. 2011). The use of the precedent design guidelines may allow for partial avoidance of such problems, or at minimum, for identification of the weak points ahead.

The limits of the design guidelines for reuse strategies need also to be highlighted. First of all, characteristic to all guidelines is that they tend to be rather generic, which means they should be applicable to most of the products. Designers need to adapt them to the case at hand, yet the resulting specifications may conflict with the guidelines traditionally used in the domain. Secondly, some of the characteristics that have been highlighted in each sphere do not contain any guidelines either for direct reuse or remanufacturing. Two main reasons can be outlined here. Number 1: the characteristic is mainly related to the company strategy and its motivation for this kind of business—e.g. economic motivation, favouring legislation. All the same, no generic guideline is applicable as it is related to the company itself. Number 2: the characteristic is inherent to the product itself and is more related to product specifications than guidelines—e.g. high initial cost, efficient product. Guidelines, company specifications and product specifications are complementary and thus, it does not matter in what manner they find their way to the designer. In practice, when using DfdR and DfRem guidelines, a risk arises that designers follow the guidelines without integrating the initial product and process specifications and therein miss out on some crucial points. Guidelines are set up to facilitate the designer's job according to previous studies. Yet, every product is distinct from the others, so that requiring specific parameters may make one guideline irrelevant and may thus not apply.

## 4 The Repurposing Strategy

A rising EoL strategy in literature concerns "repurposing". Repurposing is a third reuse end-of-life strategy that complements the two previous ones. Much like other reuse strategies, repurposing allows for retention of added-value in used products.

### *4.1 Limits of Direct Reuse and Remanufacturing Strategies*

Current reuse strategies—i.e. direct reuse and remanufacturing—aim at and succeed in preserving a part of the added-value of used products in the manufacturing of new products. The reuse process can be seen in three main issues (Fig. 3). The limits of each of them are analysed for the purpose of extracting the orientations for a complementary strategy that would increase the quantity of reused products.

The reuse strategy is a manufacturing strategy driven by market conditions. The assumption in direct reuse and remanufacturing is that the new product must at least offer the same levels of performances and of customers' satisfaction than the old product. The market can be limited by the number of like-new products that can be absorbed by the customers. The market must furthermore be open for new products. Opening the market involves upgrading or repurposing. Upgraded products are products of the initial family where performances and functions are different. Repurposed products are products that are sold for a different purpose and belong to a different product family. For example, electric vehicles' batteries can be recomposed to be reused in stationary applications.

The existence of the transformation process depends on the technical feasibility *(can the process push the product to the initial performance?),* the environmental performance *(is the reused process greener than the initial one?)* and the economic concern *(can the value chain be profitable?).* Because products are very often designed without any objective of reusing them, they cannot be disassembled


**Fig. 3** The reuse end-of-life main process

without damage and, consequently, cannot be reused. It is thus clear that design is a very important phase to improve upon. Yet there are also remanufacturing processes that cannot give back the initial performances to the product. It is clearly the case today for batteries of electric vehicles that cannot be remanufactured for the simple reason that the technology is unable to recover the initial performance at a reasonable cost (Beverungen et al. 2016). The question of what to do with the stock of such batteries is an open issue.

The collection of already-used products depends on their quality *(does the core retain the quality for the expected performance?)* and quantity *(are there enough collected used products to make the business profitable?).* Quality issues could sometimes be overlooked if the question was raised of finding new applications where technical performances are not the key issue. Quantity depends on the efficiency of the collection process and the capacity of the market to absorb more products. Alongside the economic issue, the environmental issue of waste management can likewise figure in as a significant driver of the business.

Let us explain the concept with the example of electric vehicle batteries, currently under discussion in the literature. It starts with two claims: in a few years' time, the issue of waste management will be crucial because the performance of a battery cannot be recovered by technology, while the market of stationary applications calling for batteries is however exploding. The idea is to couple both claims and see whether electric vehicle batteries, no longer efficient enough for mobile applications, can be reused after transformation in stationary applications like lighting and housing. Idjis (2015) studied a recovery network for end-of-life electric vehicle batteries from "a technical-economic, organizational and prospective perspective." He identified the business model elements (the economic viability; legal requirements) that enable the repurposing of a company to manage reverse logistics for core supply, to rely on partnerships, and assessed the effective quantity of batteries for repurposing into stationary applications as well as the properties at the end-of-use. Beverungen et al. (2016) identified and validated with experts the functional and non-functional requirements for repurposed batteries from EV to stationary applications. Based on a battery expert interview and literature (Ahmadi et al. 2014; Bauer et al. 2016; Beverungen et al. 2016), the repurposing process seems to include the same steps as reuse strategies: inspection and sorting, cleaning, dis-/re-assembly, storage, repurposing operations and testing. The repurposing step would mainly rely on reconfiguring the different components and sub-assemblies of the products and include a few product developments in order to then fulfil new requirements or connect the components in the new fashion.

## *4.2 Repurposing: Definition and Advantages*

Repurposing is a reuse end-of-life strategy that aims at preserving added-value of used products by reusing them in different applications and fields and in so doing, get around the remanufacturing and direct reuse strategies by targeting new markets.

Repurposing aims at maintaining high added-value products on the market as long as possible, to ultimately delay recycling or disposal. This strategy does not replace direct reuse or remanufacturing, but nevertheless fills a gap when these two last options are not applicable. No market cannibalisation may take place, as, the applications are distinct. This strategy should complete the list of reuse strategies and contributes to extended producer responsibility in the whole environmental consciousness equation (European Commission 2008). Company responsibility at the end of the first end-of-usage is transferred to the second life of the products. It could be done in as many cycles as possible until being transferred to the material recycling process. When the repurposing is properly implemented, the strategy is determined to be more environmentally friendly and less cost effective than manufacturing products from raw materials. The research only still has to prove in which conditions this performance may be present.

The repurposing process is close to a remanufacturing one (Fig. 4). The same types of operations are necessary, even when the combinations of parts are larger. The main difference is that the diagnostic phase on the quality of the used products collected (the product health) must be much more detailed and very intelligent in pursuit of orienting the core to the most adapted transformation process. Another difference of course lies in the technology for transforming the used product into a totally different product that must be developed, which then turns out to be easier in terms of repurposing. This strategy holds great potential for personalising new products. The principle that the performance criteria may evolve from one use to another points to real opportunity in that realm.

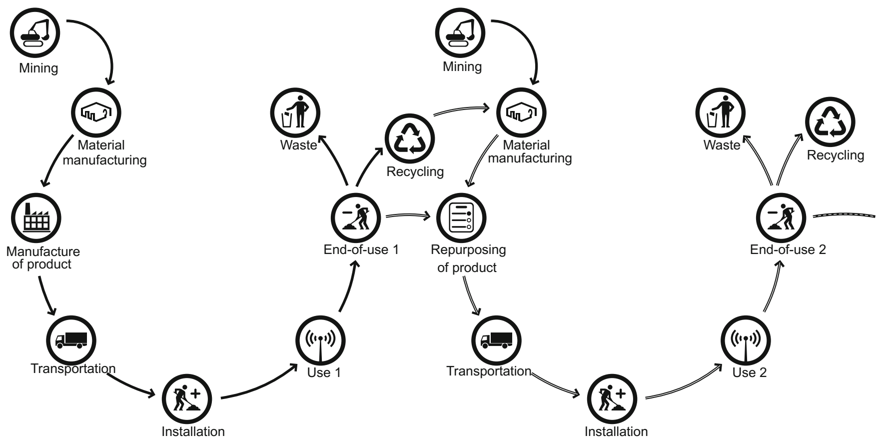


**Fig. 4** Product lifecycle for repurposing, the end-of-life strategy

### 4.3 Short Discussion on Design for Repurposing

Design for repurposing represents a completely new issue. If it seems adapted to benefit from the guidelines for reuse strategies presented above, then the perspective of the design becomes totally different, meaning that the design drivers should be re-conceptualised.

The main discussion is on determining whether the best design strategy is to design the new products from a classical design process where the constraints of input elements are new (the collected parts and materials) but known, or to design products from scratch that would have several lives in different applications. The former calls for research in defining the specifications of a repurposed product along with the design rules for transforming a product with a repurposing approach. The latter seems to be much more optimal, but the uncertainty attached to the future of the product is so high that anticipating the actual usages and the time of the first use, yields only clues about short life products. Furthermore, additional difficulty stems from the number of different applications necessary for consideration before the original design phase. The new design approach, in the both cases, should include an objective of monitoring successive lives of the product in order to help decide on the parameters of the next life once the time comes.

The literature has commenced, with Beverungen et al. (2016) and Bauer et al. (2016) already proposing some characteristics of repurposed products and repurposing production systems. The repurposed system has to be durable and reliable, which means that few instances of breaking should happen during its lifetime, while its performance should be possible to predict. Safety issues must also be addressed differently, i.e. extra life products need to consider safety as a key element for the consumer. They highlight that modularity and standardization would help to that effect. In the end, however, the principles are the same: physical characteristics of products should facilitate the repurposing process. All these points have not yet been addressed in full in the design literature and further investigations are therefore needed.

## 5 Conclusion

Design for direct reuse and remanufacturing, the end of use strategies with the most added-value retained from used products, have already become a reality in companies and are in demand by society with sustainability ambitions. While direct reuse is mainly a logistics and control issue, remanufacturing aims at getting back to the initial performances of products. These two strategies have been fully examined in studies of the last years and their main characteristics were presented according to three spheres: product dimension, manufacturing processes and business model features (P.P.BM.). The design guidelines were collected and classified for an easy use by designers.

To open minds, a valuable strategy for reusing products in different applications than the initial ones were designed for is proposed: repurposing. The concept is clarified and the main issues for the design process have been highlighted. These pursuits are promising but need investigation to find the conditions for successful deployment.

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