Design for Disassembly Criteria in EU Product Policies for a More Circular Economy

A Method for Analyzing Battery Packs in PC-Tablets and Subnotebooks

Laura Talens Peiró, Fulvio Ardente, and Fabrice Mathieux

European Commission, Joint Research Center, Directorate for Sustainable Resources, Ispra, Italy

Summary

Technological advances are increasing the complexity of products, especially those in the area of information and communication technologies. Complexity has increased in several aspects: An increased number of materials are used in products, small amounts of materials with key functions are included (i.e., rare earths in light-emitting diodes), and there are more combinations of diverse types of components and connections. The difficulty of separating parts of the products limits the development of circular economy strategies where repair, upgrade, and remanufacture prevent wasting valuable resources contained in those products. This article presents a method for analyzing the removal of battery packs in newer portable computer models, namely PC-tablets and subnotebooks, as an example on how the design of batteries can affect the life span and potential reuse of such computers. The study analyzes the difficulty of removing battery packs using the results from previous analyses of the design for disassembly of newer computer models together with audio-visual material available on the Internet. The disassembly tasks for removal of batteries are summarized by disassembly codes that could be used to help identify the design features that facilitate easier disassembly. The article goes on to discuss also how the results could be included in European Union (EU) product policies aimed to help meet some of the objectives of the European Commission’s (EC) Circular Economy Package.

Introduction

Within the field of industrial ecology, eco-design evolved as a way to evaluate the environmental impact of design alternatives during product development (Herrmann et al. 2014). The future need to disassemble a product for repair and reuse is addressed specifically by design for disassembly (DfD) (Boothroyd and Alting 1992). In the disassembly process, a product is separated into its components and/or subassemblies through non-destructive (or, at most, semidestructive) operations in order to facilitate its repair, upgrade, and reuse (Lambert and Gupta 2005). Recycling can be also favored to some extent given that during repair, some parts may be removed and fed into the recycling route while the product is sent to remanufacture and...
Design for Disassembly: Boosting Repair and Reuse

The disassembly of a product is a key factor in evaluating its potential for repair and reuse and thus to contribute to develop a more circular economy where valuable resources are kept longer. Disassembly, in some limited cases, is also crucial for recycling. From a physical perspective, a product can be defined as being a group of components that are related to one another by material connections, such as fasteners (Lambert and Gupta 2005). Besides their technological functionalities, components fulfill other functions in a product, such as protection or the transfer of forces. They can be further classified into three groups: homogenous, composite, and complex. Homogenous components are a mixture or alloy, such as casings and frames. Composite components consist of multiple materials that are irreversibly linked, such as, for instance, tires. Complex components are a set of irreversibly connected homogenous components, such as printed circuit boards (PCBs), electric motors, and cables. In general, components can be separated from the product by disassembly operations, thus keeping their extrinsic properties intact, or by destructive operations (Lambert and Gupta 2005).

The connections (types and numbers) and the architecture of the product are crucial when identifying the most convenient design strategies to facilitate disassembly and material recovery (Mathieux et al. 2008). Connections form a relationship between two components, and aim to restrict the relative movement of components. As a consequence, they greatly influence the separation and disassembly of components. Certain joining processes facilitate rapid fabrication, but may be counterproductive because they can be very costly to repair.

Table 1 shows some design strategies suggested by various researchers that facilitate the DfD of products using a
nondestructive approach. For instance, product architectures based on modular construction methods can facilitate manual disassembly through the separation and isolation of certain components, whereas other architectures can make manual disassembly more costly in terms of time and money (Güngör 2006). The architecture of the product is analyzed according to its disassembly sequence. The disassembly sequence refers to the accessibility, type of operation, and tools required to reach components (de Ron and Penev 1995). Products can be separated into components through a set of disassembly operations. Disassembly operations can be subdivided into disassembly tasks (such as the disestablishment of a connection, the movements required to transfer the subassemblies to a different location) and supplementary tasks (such as cleaning, fixturing, exchanging tools, product reorientation, and testing). The number of disassembly tasks should be kept to a minimum given that each adds to the time and cost involved; nondestructive disassembly is generally preferable. It is also best to keep the number and types of connectors to a minimum in order to avoid dependencies on other components, thereby facilitating nondestructive disassembly operations. Tools used for disassembly should also be as simple and generic as possible (i.e., standardized) to minimize the cost, also to facilitate the possible automated disassembly of components, but, most important, to prevent destructive disassembly (Güngör 2006).

A wide range of connection types are used in complex products. They vary in their ability to release fasteners, the amount of force required to undo them, their restriction of movement, and the type of fastener used. Sonnenberg (2001) classifies connectors as discrete fasteners, integral attachments, adhesive bonding, energy bonding, and other connectors. Lambert and Gupta (2005) group them into three types: single units (discrete), parts of components, and virtual components (i.e., soldered, welded), each of which they further classify as not deformed, reversibly deformed, and irreversibly deformed. The type of connector determines whether the product is to be disassembled using a destructive or nondestructive approach. Nondestructive approaches improve the quality of parts and materials that can be retrieved. For repair and reuse, parts must be recovered undamaged (Güngör 2006).

Method for Assessing the Disassembly of Critical Components in Products

The preliminary step of the method is to identify a product group whose value can be kept for longer within the economy. Relevant product groups include products that have a high volume of sales, high potential environmental impacts, and a significant amount of materials such as precious metals, copper, and other materials listed as being critical raw materials by the EC (EC 2013b). Once the product groups are selected, the next step is to define the product and gather information about its design to identify the components that have the greatest environmental impact and also may limit their repair and reuse. Information about the design is gathered by disassembling several product models and also from discussions with various stakeholders (i.e., maintenance and repair organizations, refurbishing workshops, and recycling companies). If there are only a limited number of models to be disassembled, the DfD information can also be gathered from audio-visual material available on the Internet from amateur and nonprofessional specialists and from websites such as iFixit (iFixit 2016), where anyone can create a repair manual for a device, and can also edit the existing set of manuals to improve them.

In general, audio-visual material illustrates in good detail the step-by-step instructions of how to repair and replace components in products, given that they are generally recorded to facilitate duplication by somebody else doing the same operation independently. The greatest advantage of using videos is the low investment needed to gather information compared to the purchasing of models, which can be very costly (i.e., the price of a PC-tablet ranges from €120 to 600). The only possible limitation is the availability of videos for some less-commercialized models. Results from the hands-on disassembly of diverse models and published reports can help identify the design features that favor repair and reuse. Making observations of many different models also helps understand the most common practices used by manufacturers (i.e., location of components, sealing and fastening techniques) and identify potential technical limitations of products that are difficult to address from a design perspective. Information about disassembly can be summarized using a series of disassembly codes. Disassembly codes can be defined based on the strategies for DfD presented in table 1 and are used to synthesize the number of disassembly steps and tools needed to separate a component from a product. They help understand the most frequent design option adopted by manufacturers and allow the product to be ranked according to the ease of disassembly of its components.

This method can be used to support CE policies, such as the EU Ecodesign and Ecolabel schemes. The former is a mandatory policy that aims to define the minimum performance requirements for products entering the EU market (European Parliament and the Council of the European Union 2009). The objective is to promote conception and design that can improve the energy and material efficiency of products and minimize their potential environmental impact before they are manufactured and commercialized in the EU. The EU Ecolabel is a voluntary scheme intended to inform and act as a guarantee that the product has a lower environmental impact than similar products in the market (European Parliament and the Council of the European Union 2010). This label is granted based on compliance with a set of various technological and environmental criteria.

Figure 1 shows the conceptual steps of the method applied to the batteries of portable computers. Portable computers, especially newer models, were pinpointed as one of the most relevant product groups of all 44 product groups addressed under the EU Ecodesign Directive because of their high market sales and short life span (the years during which the product is used) (Talens Peiró et al. 2016a). For instance, the global shipment of PC-tablets increased from 19 million units in 2010 to 330 million units in 2015 (Statista - The statistics portal...
The average life span of a PC-tablet has dropped from 5.1 to 2.26 years (Ely 2014; Statista - The statistics portal 2016). Battery packs were identified as being the most critical components for several reasons. They are one of the biggest parts of computers, representing around 15% of the overall mass of the product (see table S1 in the supporting information available on the Journal's website). In newer models, they are generally sealed (Bakker et al. 2014) instead of being readily separable by a spring-load release without the need of tools as in older models (see figure S1 in the supporting information on the Web). Batteries were identified as a critical component because they are crucial for the product's operation, economically feasible to reuse, and regulated by several EU directives (EC 2012, 2013a). The DfD analysis of battery packs included two steps. In the first step, data were gathered through already published studies: a study on PC-tablets by the Fraunhofer-Institut für Zuverlässigkeit und Mikrointegration (Fraunhofer IZM) and a study on subnotebook computers by the US Electronics TakeBack Coalition (Electronics TakeBack Coalition 2012; Schischke et al. 2013). In the second step, information was complemented by audio-visual material available free of charge on the Internet that gives step-by-step instructions on how to repair and replace certain parts of those models (see tables S2 and S3 in the supporting information on the Web). The outcomes were then merged to develop a series of disassembly codes based on the strategies for DfD presented in table 1. Due to data availability and differences in their design, one set of disassembly codes was developed for each computer type. For PC-tablets, the separation of battery packs is summarized in two disassembly operations (the opening of the casing and the removal of the battery pack), whereas for subnotebooks it is studied as one operation. Disassembly codes are used to rank the PC-tablets and subnotebooks according to the ease of disassembly of their battery and to identify the average and best strategies for DfD. The results of the method, as illustrated in figure 2, can help draft measures and recommendations for the DfD of batteries for product policies.

Case Studies

Batteries in PC-Tablets

Information on disassembly was available from an analysis supported financially by the Green Electronics Council (Schischke et al. 2013). Schischke and colleagues (2013) assessed the ease of dismantling 21 PC-tablets by experimental teardowns, with the aim of analyzing the opening of the device, removal of the battery packs, and dismantling of the mainboard and dismantling of the remaining parts. The data set included the number of screws/ clips, type of screws, amount and type of adhesive (i.e., one-sided, two-sided, or heated), number of tools and special tools, the number of connectors, and the number of disassembly steps involved. The disassembly steps were not fully described for all the units, and therefore an assessment based entirely on this report was not sufficient to find the main similarities and differences between the DfDs of models.
Additional information about the DfD was then gathered through audio-visual material freely available on the Internet (see table S2 in the supporting information on the Web). For this, it was necessary to identify the brand name of each of the units (as they were originally masked). Brand names were assigned by cross-checking images given by Schischke and colleagues (2013) with available videos. For models that were relatively less popular in the market, videos were not yet available and consequently only 16 of the 21 models analyzed by Schischke and colleagues (2013) were finally identified. For the remaining five models (i.e., manufactured by Odys, Intenso, and Blaupunkt), disassembly steps and tools were assessed based exclusively on Schischke and colleagues (2013). The description of disassembly steps, together with the type of tools, was later summarized by a disassembly code for the opening and a code for the removal of battery packs. The disassembly codes served to rank and estimate the number of models with better DfD. For each code, table 2 gives a description of the disassembly steps, the tools requested, and the number of models of PC-tablets with such features. For the opening, four alphabetical disassembly codes were defined, from code A (PC-tablets that are easier to open) to code D (those models that require a more intensive disassembly process). Analogously, four alphabetical codes were also defined to describe the disassembly steps needed to remove the battery packs. Code A was assigned to PC-tablets with battery packs that can be easily separated by pressing a spring-load release, whereas models under code D required additional steps, such as the peeling away of adhesives and unscrewing or unplugging of connectors. For codes B, C, and D, additional numerical codes were defined to represent the number of connectors required to unplug the battery (i.e., the number “1” indicated that up to three connectors had to be unplugged, and “2” that more than three connectors had to be unplugged). For example, code C referred to the peeling off of adhesives whereas code C+1 meant the peeling off of adhesives and unplugging of up to three connectors.

As illustrated in table 2, eight models were opened by pressing the clips of the casing using a spudger (a tool used to separate pressure-fit plastic components and panels without damaging them), six models by pressing clips plus unscrewing and peeling off adhesive tapes, and five models by pressing clips and unscrewing. Two models required the use of a heat gun or pad to remove the glue that fixed the touch screen to the casing. Of the various designs observed, plastic clips seem to be the simplest option for fastening the casing to the display, because after pressing the clips the screen can be easily detached using a spudger. This operation can be carried out by one person by hand and/or with commonly available tools.

Regarding the steps for the extraction of battery packs, only 1 of the 21 PC-tablet models observed was designed to be able to extract the battery manually without opening the device (see PC-tablet 1 in figure 2). The other 20 models were designed with built-in battery packs that were only accessible after opening the device, and then unscrewing and/or peeling away adhesives, in addition to unplugging cables (see PC-tablet 2 in figure 2). From the audio-visual material, we conclude that small components, such as the camera, connecting cables, adhesive tapes, or the electromagnetic interference (EMI) shield, often need to be preventively removed to access the batteries. Such an operation must be undertaken with special care because the disassembly is performed to repair or upgrade batteries. Schischke and colleagues (2013) commented that, in order to facilitate repair and recycling, screws are the preferred option. However, adhesive strips can be also used to replace a multitude of screws (Schischke et al. 2013).

**Batteries in Subnotebooks**

Using as a starting point the analysis of subnotebooks included in the Electronics TakeBack Coalition report (Electronics TakeBack Coalition 2012), we studied the steps required to access and extract battery packs for subnotebook computers. The Electronics TakeBack Coalition report aimed to highlight the fact that batteries in subnotebooks could not be replaced by users. It provided an analysis of 28 models (including their brand names), for each of which it indicated whether batteries were user-replaceable and easy to remove, and described the specifications and the product warranty conditions. Websites

![Figure 2](image_url)  
*Figure 2* Two PC-tablet models analyzed. The location of the battery packs is indicated by pink dotted lines.
### Table 2
Disassembly codes, steps and tools needed to open the casing and remove the battery packs from PC-tablets

| Code | Disassembly steps                                                                 | No. | Disassembly tools                                | No. of units | %  |
|------|----------------------------------------------------------------------------------|-----|-------------------------------------------------|--------------|----|
|      | **Target: opening the casing**                                                   |     |                                                 |              |    |
| A    | Remove the casing by pressing clips                                             | 1   | Spudger                                         | 8            | 38 |
| B    | Remove the casing by pressing clips and unscrew                                  | 2   | Spudger and screwdriver                         | 5            | 24 |
| C    | Remove the casing by pressing clips, unscrew and peel adhesive tape               | 3   | Spudger and screwdriver                         | 6            | 29 |
| D    | Remove the casing by prying out glue, or pry out glue and unscrew                 | 2   | Heat gun/pad and screwdriver                    | 2            | 10 |
|      | **Target: removing battery packs**                                               |     |                                                 |              |    |
| A    | Press spring-load release (no opening needed)                                    | 1   | None                                            | 1            | 5  |
| B    | Unscrew                                                                          | 1   | Screwdriver                                     | 1            | 5  |
| B+1  | Unscrew and pull connectors (up to three)                                        | 2   | Screwdriver, spudger                            | 2            | 10 |
| C    | Pry out glue                                                                     | 1   | Heat gun or heat pad, spudger                   | 2            | 10 |
| C+1  | Pry out glue and pull connectors (up to three)                                    | 2   | Spudger                                         | 5            | 24 |
| D    | Peel adhesive/s and unscrew                                                      | 2   | Screwdriver, spudger                            | 1            | 5  |
| D+1  | Remove adhesive and unscrew, plus up to three connectors                          | 3   | Screwdriver, spudger                            | 6            | 29 |
| D+2  | Remove adhesive/s and unscrew, plus remove more than three connectors             | 3   | Screwdriver, spudger                            | 3            | 14 |

Source: Elaborated based on Schischke and colleagues (2013).

that gave information about the removal of battery packs were also listed. The report targeted the potential buyers and users of subnotebooks, and therefore the information was given in informal language (i.e., “lots to disassemble first,” “yes torx needed,” “very easy,” or “yes but many parts to remove”). In order to further understand the disassembly sequence for each of the models described in the report, we developed a more exhaustive study using audio-visual material that illustrated the disassembly sequence required to reach battery packs. Videos were available for 25 of the 28 models originally analyzed (see table S3 in the supporting information on the Web). The disassembly sequence of the remaining three models was deduced using their technical descriptions and assuming some design similarities between models manufactured by the same companies.

Table 3 gives the type and number of disassembly steps as well as the tools associated with each disassembly code. Alphabetical codes (from A to F) were designed to synthesize information about the disassembly steps, and tools for disassembling PC-tablets were developed (see table 3). For the disassembly codes C, D, and E, the number of additional steps required to extract battery packs are further described using numerical values placed before or/and after the disassembly code. For example, the disassembly code C means that, in order to extract battery packs, the base cover needs to be opened, and then the battery has to be unplugged and unscrewed. Code 1+C means that, before removing the base cover, rubber feet covering screws or a side connector cover need to be removed.

Only 2 of the 28 subnotebooks analyzed had external rather than built-in battery. In one of these, the battery could be separated manually without tools (see subnotebook 1 in figure 3). For around half of the models analyzed, the batteries could be extracted in three steps: removing the base cover; unplugging the battery from the main PCB; and unscrewing it from the chassis. The other models required additional steps before
Table 3  Disassembly codes, steps, and tools needed to open the casing and remove the battery packs from subnotebooks

| Code | Built-in battery? | Disassembly steps | No. | Disassembly tools | No. of units | % |
|------|-------------------|-------------------|-----|-------------------|--------------|---|
| A    | No                | Press spring-load release | 1   | None             | 1 (No. out of 28) | 4  |
| B    | No                | Unscrew battery pack | 1   | Screwdriver      | 1 (No. out of 28) | 4  |
| C    | Yes               | Remove base cover, unscrew and unplug battery pack | 3   | Screwdriver      | 13 (No. out of 28) | 46 |
| 1+C  | Yes               | Steps described in C plus one prestep. For example, remove rubber feet or connector cover. | 4   | Screwdriver      | 2 (No. out of 28) | 7  |
| 2+C  | Yes               | Steps described in C plus two presteps. For example, remove rubber feet, remove connector shell, and/or unscrew. | 5   | Screwdriver      | 2 (No. out of 28) | 7  |
| 1+C+I| Yes               | Steps described in C plus one prestep and one poststep. For example, remove rubber feet, remove connector shell, peel adhesives, and/or unplug additional cables. | 5   | Screwdriver      | 2 (No. out of 28) | 7  |
| D    | Yes               | Remove base cover, peel adhesives, unscrew and unplug battery pack | 4   | Screwdriver      | 2 (No. out of 28) | 7  |
| 2+D  | Yes               | Steps described in D plus two presteps. For example, remove rear panel and HDD unit. | 6   | Screwdriver      | 1 (No. out of 28) | 4  |
| E    | Yes               | Remove base cover, connectors, lift tape, unscrew and unplug battery pack, and pull without disconnecting speakers cables | 6   | Screwdriver      | 2 (No. out of 28) | 7  |
| F    | Yes               | Unscrew base cover, turn the computer and press the tab in to loosen the keyboard, unplug the keyboard cable, unplug and remove the palm rest, unscrew battery and lift it out of the laptop | 6   | Screwdriver      | 1 (No. out of 28) | 4  |
| 5+F  | Yes               | Steps described in E plus 5 presteps. For example, remove SD blank, unscrew and remove access door, remove the memory and remove screws | 11  | Screwdriver      | 1 (No. out of 28) | 4  |

Source: Elaborated from Electronics TakeBack Coalition (2012).
HDD = hard disk drive; SD = Secure Digital memory card.

and/or after removing the base cover. For some models, special care had to be taken in order to not disconnect other cables. In one of the models analyzed, in addition to unscrewing the base cover, the keyboard and palm rest also needed to be removed (see subnotebook 2 in figure 3) (Paine 2014; PSAParts 2013).

**Discussion: How Can EU Product Policies Make Products More Circular?**

The results of the case studies show that the disassembly of the critical components of products can be analyzed systematically to identify design features that hamper repair and reuse, thus enhance a more circular economy. In this respect, the Communication on the Circular Economy (EC 2015a) refers to several EU design-related instruments, such as the Ecodesign Directive (2009/125/EC) and the EU Ecolabel Regulation (1980/2000) (European Parliament and the Council of the European Union 2009, 2010). These instruments can be used independently or in combination to improve the overall performance of products on the market. Discussions during the formulation of requirements and criteria for DfD are closely followed by all of the stakeholders involved in the life cycle.
APPLICATIONS AND IMPLEMENTATION

Figure 3 Analysis of two subnotebook models. The location of the battery packs is highlighted by pink dotted lines (Doe 2013).

of products in order to understand possible technical limitations that may prevent the implementation of DfD, such as the functionality of the product, its life span, and the ultimate recovery of materials. Special attention needs to be given to the technical limitations in order to understand the potential improvements in product design and the potential for a more circular economy.

Design for Disassembly Criteria for the EU Ecolabel

The results of the present article, as illustrated in tables 2 and 3, have already been used to formulate some DfD criteria in the revised EU Ecolabel for portable computers (Talens Peiró et al. 2016b). The proposed criteria aimed to restrict the use of glue and welding in the product for the assembly of batteries and establish a maximum number of steps for their disassembly. As illustrated in table 2, there are many possible combinations of disassembly codes for opening and removing batteries that can be used to establish the maximum number of steps when formulating DfD criteria. Thresholds for the maximum number of steps for each PC model were drafted, based on the results of analyzed computer units, and discussed with stakeholders (including computer manufacturers, association of consumers, nongovernmental organizations, recyclers, and policy makers).

The availability of a repair manual with clear disassembly and repair instructions to enable nondestructive disassembly was also found to be beneficial. Moreover, marking the location of screws (e.g., using printed arrows) would facilitate their visibility and the opening of the casing. Table 4 shows the proposed draft criterion for the DfD of batteries, which is currently under discussion for inclusion in the final EU Ecolabel criteria for computers (JRC-IPTS 2014).

The findings of this article could also be used to develop mandatory requirements in the preparation of the EU Ecodesign regulation for computers (EC 2016). Eco-design regulations are more binding than the EU Ecolabel scheme because they must be complied with when placing new products on the market. Eco-design requirements shall therefore be formulated considering some of the most commonly used manufacturing practices and targeting the worst methods.

Another important message to pass on from this article is that the various policies need to be harmonized and complemented, such as, for instance, the previously cited directives and communication with the recent directive 2013/56/EC amending directive 2006/66/EC on batteries and accumulators. This latter directive introduced an article about the removal of waste batteries and accumulators, stating that batteries “shall be readily removable, if not by the end-user by qualified professional independent of the manufacturer. Appliances incorporating batteries and accumulators shall be accompanied by instruction about how they can be removed” (EC 2013a, L329/7). The study described in this article shows that this legal requirement is clearly not met by some of the analyzed models. Indeed, some of the audio-visual material accessible through the Internet was originally published to address the lack of available instructions about the disassembly steps needed to access and replace.
components, such as battery packs, in the latest portable computers. Companies such as Newpower99, Fixez, Directfix, and ifixit have identified this lack of information and the development of some disassembly tools as a business opportunity and have started to provide services for the repair and reuse of parts (ifixit 2016; newpower99 2016; fixez 2016; directfix 2016). Nevertheless, the availability of audio-visual material for repair can be also crucial to facilitate the recycling of batteries and computers. From several visits to waste treatment operators, we observed that instructions available on the Internet for the separation of battery packs from computers are generally not systematically checked. It is, instead, common practice to apply destructive methods to separate batteries, or to treat the whole product by mechanical processes (i.e., shredding) without preliminary disassembly. Batteries in waste electrical and electronic equipment (EC 2012) need to be addressed, particularly with regard to their recycling. An interview study of Nordic corporations found that manufacturers welcome Ecodesign rules that improve product durability and enable further recycling (Dalhammar 2016). A requirement on DfD of batteries could therefore be well received as being beneficial to consumers and society.

**Conclusion**

This article presents a method for analyzing the DfD of critical components in products, in order to facilitate their replacement and reuse and thus change the traditional take-use-dispose economy. The method is based on a definition of disassembly codes that describe the various tasks that need to be undertaken to reach target components. These codes, which were based on DfD strategies, were developed to rank the design of battery packs in two types of computers—PC-tablets and subnotebooks. Although it initially seemed that the same disassembly codes could be used for both models, this was difficult in practice given the differences in their designs. The development of unique disassembly codes was also limited by the availability of already existing data and the lack of a budget to purchase models to test. Audio-visual material available on the Internet was used as a useful and novel approach for gathering information about disassembly.

The method proposed proved to be applicable to different computer models and could therefore be used to systematically identify and analyze design features that hamper repair and reuse in other electrical and electronic products. As part of the method, the disassembly of battery packs in PC-tablets was summarized using two disassembly codes, whereas one disassembly code was sufficient to summarize the operations required to disassemble batteries in subnotebooks. For PC-tablets, only 2 of the 21 models analyzed had readily separable batteries, and the battery pack was separable in only 1 of the 28 subnotebook models analyzed. The design of those few models proved that it is possible to design readily separable batteries.

The security of the supply and price volatility of raw materials are both great challenges to Europe. Given the potential risk of the supply and the high economic importance of critical raw materials, the value of products should be maintained through better management of their life span, as mentioned in the latest Communication on the Circular Economy (EC 2015a). From an environmental perspective, it is important to further study how the life span of a product influences its overall environmental impact, as in the analysis carried out of washing machines and dishwashers (Talens Peiró et al. 2014; Ardente and Mathieux 2014b; Bobba et al. 2016). For electrical and electronic products with fast-changing market conditions, DfD strategies could help to significantly slow down their potential volume in the waste flow. As discussed by (Bakker et al. 2014), it is crucial to understand when and how to extend the product’s life without compromising the product’s economic viability. In the case of newer computer models, the design of readily separable batteries will facilitate their repair, remanufacture, and reuse. The results of the DfD of newer computer models are also in line with the four major strategies to improve material efficiency proposed by (Allwood et al. 2011): longer-lasting products; modularization and remanufacturing; component reuse; and designing products with less material. DfD strategies could also be further accompanied by the promotion of new business models that facilitate reverse logistics and create jobs in the maintenance and refurbishing sectors. DfD also plays a key role in optimizing the separation of critical components that may require special treatment operations, and in improving the recovery of materials at the end-of-life stage that can help advance toward a CE.

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Supporting Information

Supporting information is linked to this article on the JIE website:

Supporting Information S1: This supporting information includes three tables and one figure. Table S1 shows the material bill of an exemplary laptop computer. Figure S1 presents the disassembly sequence for a laptop computer. Tables S2 and S3 provide links to the audio-visual materials analyzed for the disassembly of PC-tablets and of subnotebooks, respectively.