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Ruud Balkenende, Conny Bakker

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Design Strategies

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Design for a circular economy emphasises the importance of recovery of products and materials, if possible, through maintaining the performance and value of a product over multiple use cycles. Preferred recovery operations are reuse, repair, refurbishment, remanufacturing and parts harvesting, as these processes maintain or restore the functionality of products and parts. Furthermore, enabling the recycling of materials is an essential step, although also a last resort. In design this brings about the need for strategic thinking and a long-time horizon with increasing attention to business models.

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Introduction

Instead of "less is more," we can now say: "endless is more."
(William McDonough, https://www.greenbiz.com/article/davos-meets-circular-economy)

Through the design of products, materials are shaped and combined with other materials, often in a complex way, leading to highly integrated products. The energy and effort put into the sequence of manufacturing processes determines the functionality, quality and value of a product. Surprisingly, at the end-of-life of a product we take it for granted that its functionality, all the energy put into manufacturing as well as its value will be lost. Most products are simply wasted, i.e. landfilled or incinerated. This leads to a large environmental burden and significant economic loss. To avoid this, the recovery of products and their constituent materials should be explicitly addressed in the design of products. Although recycling is receiving increasing attention, implying that at least part of the materials and a fraction of the value are recovered, this hardly reduces the losses. To maintain environmental quality and economic value, dealing with products in a different way is a necessity. Repairing a product that is broken or upgrading a product that is still functional. This asks for a change in the way in which products are designed, made, sold, used and treated at the end of a life cycle. This is essentially what circular product design is about. In this chapter we will outline how the principles of circular economy can be implemented in the design of products and services.

Designing for a circular economy

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has been the focus of design for sustainability over the pa
Design for sustainability integrates environmental aspects in
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the focus has been largely on optimising the material usage
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materials. This has led to considerable improvements in
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Designing for a circular economy

Starting with the broader context, the major driver of the transition to a circular economy is the need for a more sustainable world. We face a number of urgent global problems that are summarised in the United Nations Sustainable Development Goals. Design offers great opportunities to improve the environmental performance of products. This has been the focus of design for sustainability over the past 25 years. Design for sustainability integrates environmental aspects in the design of products and services and aims to reduce negative environmental impacts while maintaining the performance of a product. In practice the focus has been largely on optimising the material usage and energy consumption of products, and on increasing the amount of recycled materials. This has led to considerable improvements in the design of products, in part also stimulated by regulations that have enforced companies to follow an eco-design approach. However, results are only implemented at an incremental pace, and as our challenges have increased new technologies have emerged. Instead of trying to solve environmental issues we should step up to preventing them. It is time for a next step in design for sustainability, and it is time to increase the impact of what designers do. This is where design for a circular economy comes in. Instead of saving just materials, we can save functionality and value. To achieve this, the loop must be closed at the level of the user, the level of the service provider or the level of the manufacturer. This will only work when not only environmental impacts, but also business and user aspects are taken into account. This means a more complex approach, which is strongly promoted in design for the circular economy.

Circular economy is not yet a well-defined scientific concept. A recent paper (Kirchherr 2017) made an inventory and found 95 different definitions. Therefore, it is necessary to clearly describe what we consider the core values of a circular economy. We will not do this by adding another definition but by noting the aspects that we consider essential. First the ultimate aim of CE: this is sustainable development, implying environmental quality, social equity and economic attractiveness. The positive economic approach, in particular, makes CE stand out. Increasing product lifetime by making products more durable and by enabling recovery of product functionality, not only minimises environmental impact, but also has the potential to maximise economic benefit. This perspective helps companies to see the opportunity to really combine sustainability with a business approach that is versatile.

All this requires taking a systemic approach, a second essential aspect of CE. It has been inspired by influential holistic strategies, like *Biomimicry* (Benyus 1997) and *Cradle-to-Cradle* (McDonough & Braungart 2002). These aim for closing resource loops by optimizing systems instead of improving the components within a system, and have inspired many companies and designers to explore new solution spaces. The high level of abstraction of these strategies, however, makes

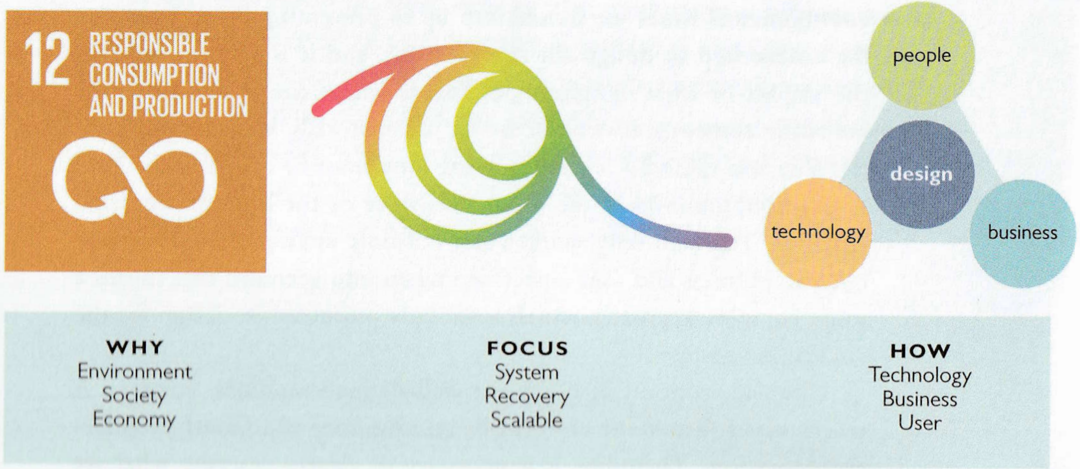

Figure 1. Aspects that we consider essential to the concept of Circular Economy.

it difficult to directly implement them. Although inspiring, tend to be dogmatic, making practical application difficult companies. In contrast, circular economy provides a more p approach, recognizing that closing loops from a business pe requires addressing not only material related issues, but also models, logistics and financing, and actively encouraging com explore new directions that explicitly include recovery.

Recovery is a third essential aspect of CE. The emphasis on opportunities for reusing or remaking a product by recovery o like reuse, repair, refurbishment, remanufacturing and parts h is a distinguishing aspect of a circular economy compared to t tional linear economy. For these aspects to work, we need kn that enables practical implementation, for instance regarding ble business models, or regarding technological developments i facturing, data acquisition and data management. The final cor often undervalued, is the way people deal with products and their behaviour and their acceptance of new offerings.

The implications of the transition to a circular economy for and service design are considerable. Although product design integrates knowledge of people, business and technology, our way of designing misses out on the recovery of products and n Therefore, two basic questions that should be addressed from a product design perspective are:

- How can we change the design process of products and servic make recovery an integral part of design?
- And how can we implement this in the actual design process a takes place within companies?

Because only then will circular product design be able to rea and have a real impact on society. In this chapter we will fo recovery (the first question) as an integral part of the design pro essential. First the ultimate aim of CE: this is sustainable development, implying environmental quality, social equity and economic attractiveness. The positive economic approach, in particular, makes CE stand out. Increasing product lifetime by making products more durable and by enabling recovery of product functionality, not only minimises environmental impact, but also has the potential to maximise economic benefit. This perspective helps companies to see the opportunity to really combine sustainability with a business approach that is versatile.

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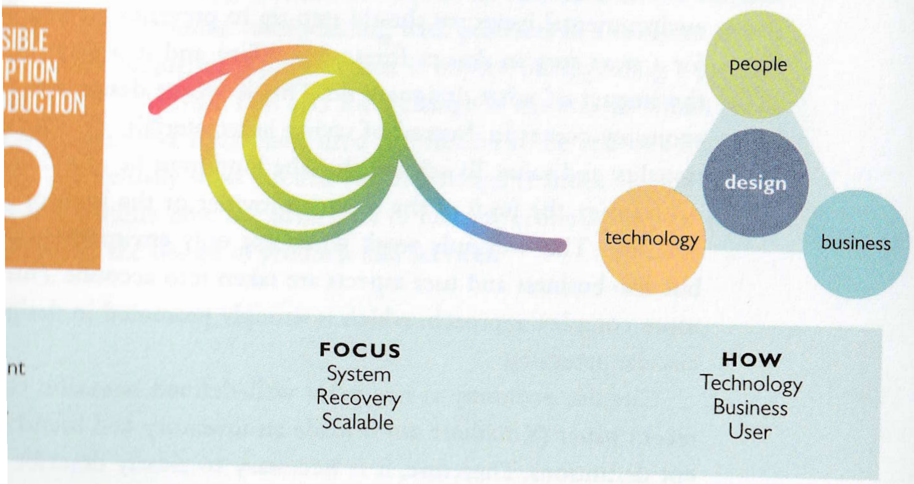

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Recovery is a third essential aspect of CE. The emphasis on creating opportunities for reusing or remaking a product by recovery operations like reuse, repair, refurbishment, remanufacturing and parts harvesting is a distinguishing aspect of a circular economy compared to the traditional linear economy. For these aspects to work, we need knowledge that enables practical implementation, for instance regarding sustainable business models, or regarding technological developments in manufacturing, data acquisition and data management. The final core aspect, often undervalued, is the way people deal with products and services, their behaviour and their acceptance of new offerings.

The implications of the transition to a circular economy for product and service design are considerable. Although product design already integrates knowledge of people, business and technology, our current way of designing misses out on the recovery of products and materials. Therefore, two basic questions that should be addressed from a circular product design perspective are:

- How can we change the design process of products and services to make recovery an integral part of design?
- And how can we implement this in the actual design process as it takes place within companies?

Because only then will circular product design be able to reach scale and have a real impact on society. In this chapter we will focus on recovery (the first question) as an integral part of the design process.

Recovery as an intrinsic part of design

The classic product innovation process models that have been developed over the past 40 years (see example in Figure 2) describe how product development moves in a relatively straight line from a strategic stage, where the need for a new product is determined, to the more operational stages concerning detailed design, production, marketing, distribution and eventually, product use. None of these models, however, considers how a product can be recovered at the end of its functional life.

Adding the recovery step to the strategic models of the product innovation process is a crucial addition (see Figure 3). The recovery stage describes what happens to a product after 'use.' It includes reuse, refurbishment, remanufacturing and recycling. Designers use models like these to plan and organize the design process, and to discuss and communicate the various steps with each other and with clients. They also use the models as checklists when drawing up a program of requirements. In other words, these product innovation process models are part of designers' mental models of the design process – they form a kind of shared language. And when a step such as recovery is missing from these mental models, it will not be addressed during design, at least not structurally, risking the situation that topics such as sustainability and circularity will not exert strategic influence on product policy and product planning beyond legal compliance.

Just as technology links user and business from the perspective of manufacturing and functionality, so does recovery link user and business from the perspective of a complete and closed life cycle. In circular product design it is essential that such a life cycle perspective is already present at the initial conceptual level of product design. Adding recovery thus implies that all actions that might be needed after the use of a product should always be taken into account. By making circularity an explicit but integrated part of the design concept, opportunities to start a new cycle instead of wasting the product will become part of the

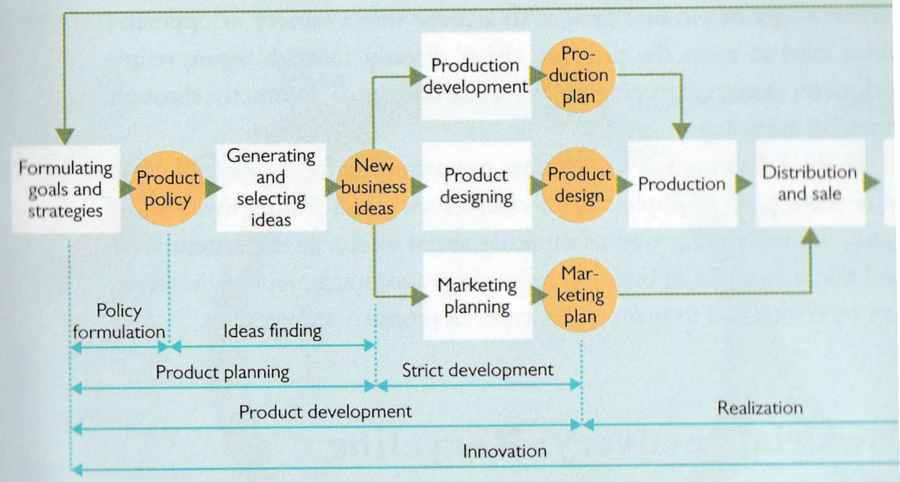

Figure 2. The original Product Innovation Process model by Roozenburg and Eekels (1991). The product recovery step, after 'use,' is missing.

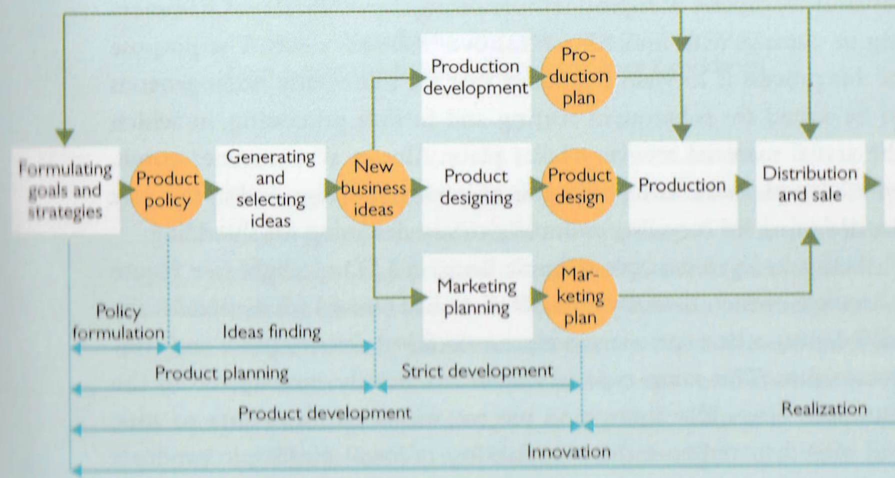

Figure 3. The adapted Product Innovation Process model, with the recovery step added (by Bakker).

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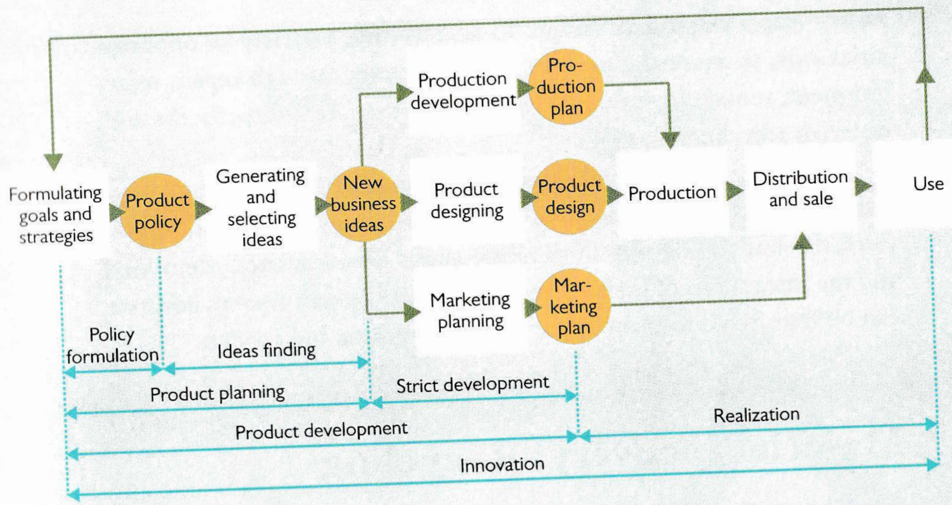

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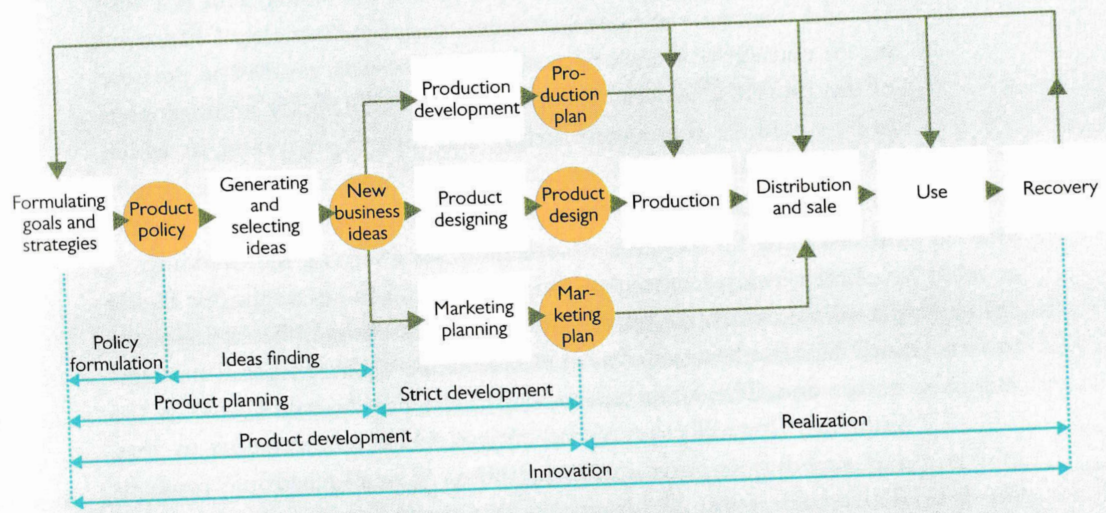

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earliest stages of product design. To achieve this, a variety of opportunities exist to reuse the product, either directly, through repair, refurbishment, remanufacturing or parts harvesting, or indirectly through materials recycling.

In the following we will explore opportunities for design and illustrate these with examples. The examples are taken from a diversity of cases, the underlying way of thinking about effects at the system level and the integration of business, technology and human aspects, however, can be transferred to many other types of products and services.

Material recovery: Recycling

Recycling is the outer loop of circular economy. Materials are recovered, but product functionality is lost (Figure 4). It can be considered a last resort, but recyclability is also a prerequisite for any product once extension of its useful life is no longer possible. The first step in the recycling process for most products is shredding. This is a very forceful treatment of a product, consisting, for example, of hammering or cutting, with limited control over the final result. The purpose of this process is to yield fragments that are sufficiently homogeneous to be suited for subsequent sorting and further processing, in which the actual material recovery takes place. Almost all consumer goods, whether a phone, a hairdryer, a pair of jeans, or a fridge, end in this way. So, designing for recycling essentially means designing for shredding.

Let's take as an example a simple lamp, an LED spotlight (see Figure 5, top left), which basically consists of an LED board (that contains the LED lights), a heat spreader, an electronic driver for the LEDs and connector pins. This lamp type has been extensively investigated in the European GreenElec innovation project, which ran from 2011 to 2015, and aimed to improve the recyclability of small electronic products (Balkenende 2014). The fragments that result after shredding the LED lamp are not homogeneous but contain many different materials that are stuck together and cannot be recycled simultaneously. The electronics

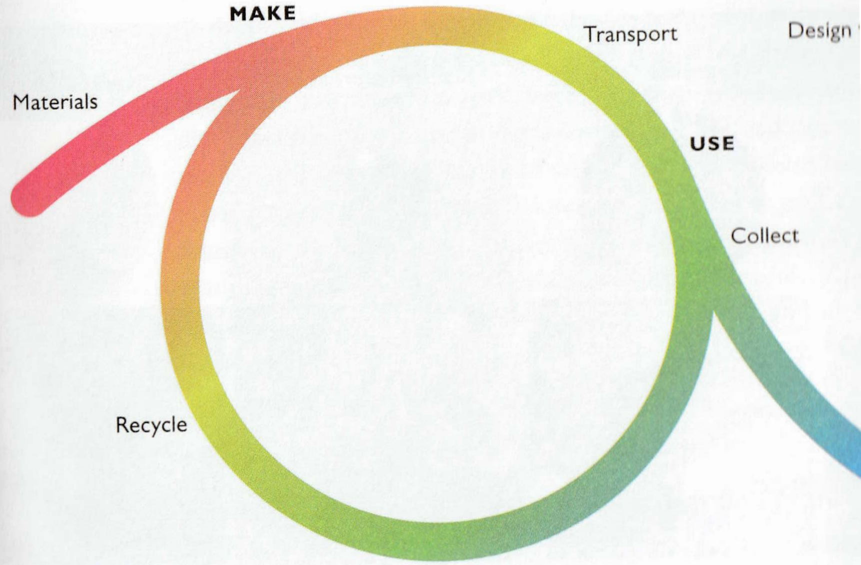

Figure 4. The product life cycle for products in a linear economy. Although recycling takes place to some extent, from a design perspective the result is often coincidental.

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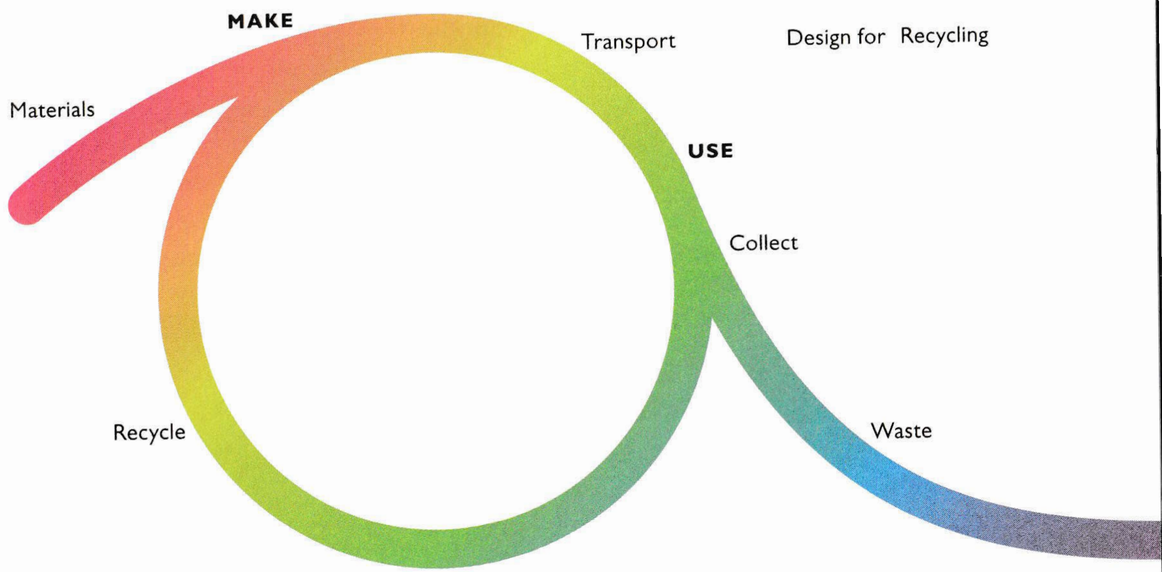

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for instance largely remain fixed to the aluminium heat spreader due to the screw connections between them. This is problematic, because aluminium and printed circuit boards need to be separated in order to be successfully recycled. With this specific product, about 40% of the weight, mainly aluminium, is recovered in the end. However, most of the more valuable materials present in the electronics (such as copper, silver and gold) are lost.

The lesson learned is that it is not sufficient to have products with only recyclable materials; in the recycling process these materials should also become disconnected, because otherwise they cannot be recovered. A number of LED lamps were redesigned taking these two simple rules

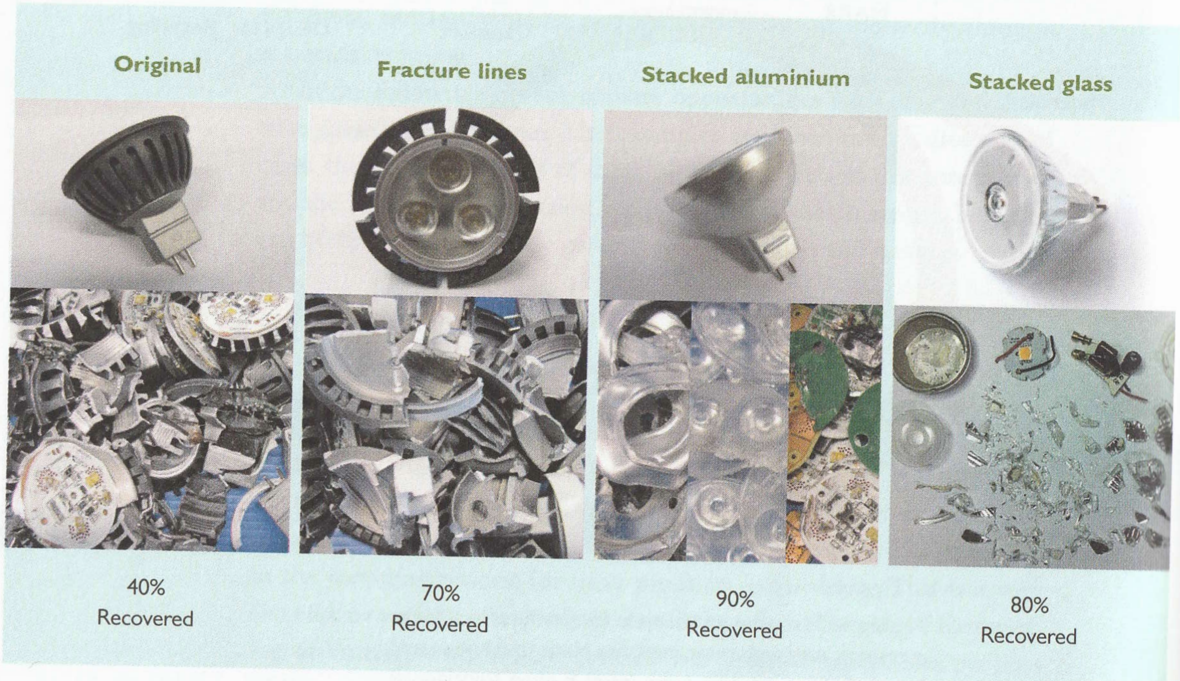


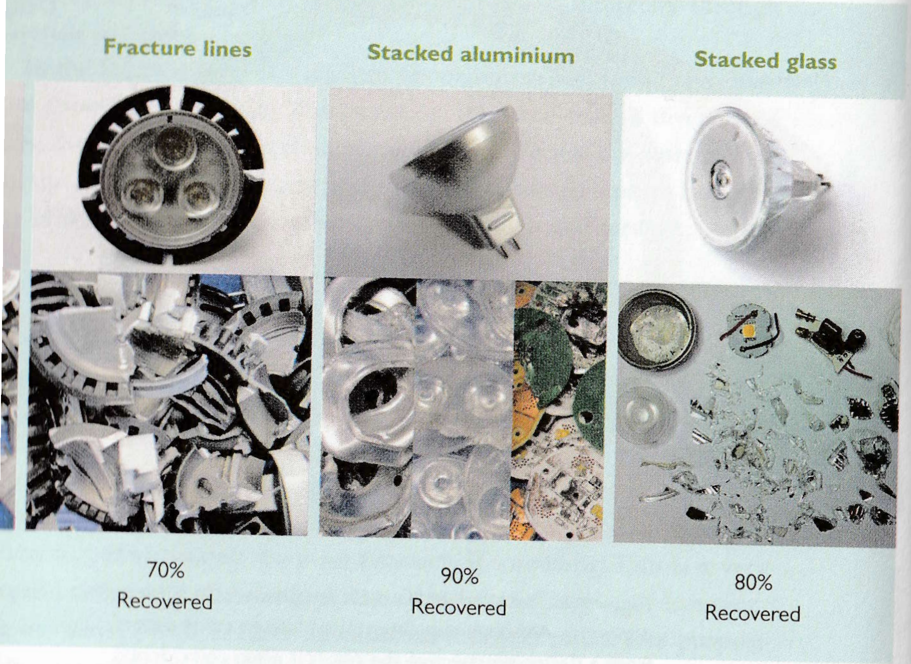
Figure 5. A LED spot light (top left) and three redesigns employing different materials and connections to improve the recycling result. The images at the bottom show typical fragments resulting from a shredding test. Recovered fractions are given in weight-%.

into account: the lamps consist of recyclable materials and they have connections that break easily in the recycling process. This resulted in a variety of design solutions. In the existing LED lamp, the focus was on breaking down the screw connection during the shredding process. This was achieved by adding fracture lines along the screw holes. The fracture lines guide fragmentation during the shredding process (without hampering reliability during normal operation). A shredder test resulted in considerable improvement of the homogeneity of fragments and

therefore much better separation of different materials, with 7c materials recovered (see Figure 5).

In the subsequent redesigns of the lamp, the requirements recycling were already considered at the start of the design pro internal connection was completely eliminated, and different choices were made. The redesigns have been described in more elsewhere (Aerts 2014), but here we summarise the main resul redesigns, no fixed internal connections were used, and the material was made more uniform to eliminate the non-re plastic originally used. Small-scale shredding tests showed very ing results with recovery of 80 to 90% of the materials. In b most of the LED boards were released and could be separat thermore, the cost of the newly designed lamps were the same than that of the original. This implies that such redesigns are from the perspective of the manufacturer and contribute to i revenues once it comes to recycling. By setting the probler right way and dealing with it in the early design stage, a new space was opened up.

In design for recycling, special attention should be give use of highly tailored 'materials' that are crucial to many app What we call a material is actually often a complex combina number of materials. Composite materials, which have uniq erties that can be tailored to a large extent to make them ve for specific applications, are a prominent example. This ran the complex layered structures used, for example, in airpl wind turbine blades to the elastomer coating on textile fib tronics, where up to 50 different elements are highly inte small volumes, form another example. Additional complicati when embedding electronics in all kinds of products, for ins adding sensors and connecting them to the Internet. Luminou in which electronic wiring and LEDs are interwoven with t and the incorporation of electronics in objects made by 3D are other examples where the degree of integration will ha proper end-of-life treatment of a product. We encounter these



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In the subsequent redesigns of the lamp, the requirements regarding recycling were already considered at the start of the design process. The internal connection was completely eliminated, and different material choices were made. The redesigns have been described in more detailed elsewhere (Aerts 2014), but here we summarise the main results. In the redesigns, no fixed internal connections were used, and the housing material was made more uniform to eliminate the non-recyclable plastic originally used. Small-scale shredding tests showed very convincing results with recovery of 80 to 90% of the materials. In both cases most of the LED boards were released and could be separated. Furthermore, the cost of the newly designed lamps were the same or lower than that of the original. This implies that such redesigns are attractive from the perspective of the manufacturer and contribute to improved revenues once it comes to recycling. By setting the problem in the right way and dealing with it in the early design stage, a new solution space was opened up.

In design for recycling, special attention should be given to the use of highly tailored 'materials' that are crucial to many applications. What we call a material is actually often a complex combination of a number of materials. Composite materials, which have unique properties that can be tailored to a large extent to make them very suited for specific applications, are a prominent example. This ranges from the complex layered structures used, for example, in airplanes and wind turbine blades to the elastomer coating on textile fibers. Electronics, where up to 50 different elements are highly integrated in small volumes, form another example. Additional complications arise when embedding electronics in all kinds of products, for instance by adding sensors and connecting them to the Internet. Luminous textiles in which electronic wiring and LEDs are interwoven with the fabric, and the incorporation of electronics in objects made by 3D printing, are other examples where the degree of integration will hamper the proper end-of-life treatment of a product. We encounter these materials in textiles, furniture, electronic equipment, but also in cars, airplanes, wind turbines, and even in bridges. In most applications these materials are essential for performance and therefore difficult to replace. Due to their tailored properties, reuse is very difficult and unfortunately, due to the mixing of materials, recycling is almost impossible. Here new design strategies need to be developed that already consider next use cycle of the materials when designing products which employ them.

Through design for recycling we can ensure that the materials in a product are recovered as best as possible. Applying recovered ('recycled') materials in new products is also an important part of design for recycling. An inspiring example in the field of textiles is the use of 100% recycled yarn by Interface, a global manufacturer of carpets, in their Net Effect tiles (Pauw 2015). The nylon of these tiles is sourced by collecting discarded fishing nets from oceans and beaches. In addition to the use of recycled nylon, a random pattern is applied in a smart way, hiding quality variations in the nylon. Further, Interface started applying polyvinylbutyral, obtained from recycled car windows, to replace the latex in the precoat that takes care of adhering the yarn to the tile backing. This decreases the environmental load of the precoat by 80%.

Product and part recovery: repair, refurbishment, remanufacturing and parts harvesting

To maintain or recover functionality at the end of the life cycle of a product, i.e. to enable a subsequent life cycle, products can be reused, repaired, refurbished or remanufactured. If complete products cannot be recovered, it might be worthwhile to harvest some of their parts and refurbish or remanufacture them (Figure 6). Repair, refurbishment and remanufacture are differentiated according to the quality of the recovered product relative to the original. In the case of remanufacturing, the product gets an extensive overhaul and is brought back at least to

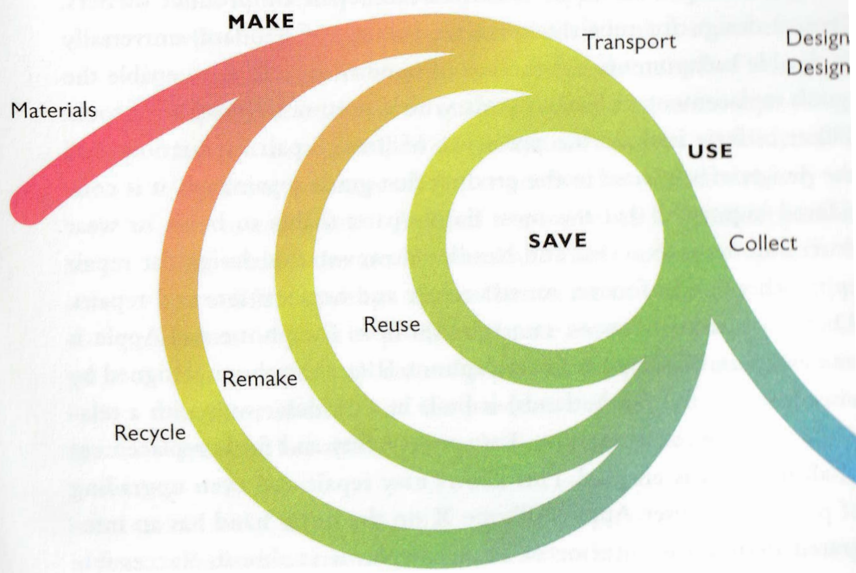

Figure 6. The product life cycle for products in a circular economy. The emphasis is on keeping products and materials in use through recovery operations.

Original Equipment Manufacturer (OEM) specification
2017). In the case of repair and refurbishing, the process is le
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be inferior to the original specification (Gray 2007). The h
treatment of a product at the end of a life cycle is to a l
similar, although repair is usually a limited operation (e.g.
tyre or replacing a broken zipper) whereas refurbishment a
facturing require more elaborate processes, involving ope
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such operations.

in textiles, furniture, electronic equipment, but also in cars, airplanes, wind turbines, and even in bridges. In most applications these materials are essential for performance and therefore difficult to replace. Due to their tailored properties, reuse is very difficult and unfortunately, due to the mixing of materials, recycling is almost impossible. Here new design strategies need to be developed that already consider next use cycle of the materials when designing products which employ them.

Through design for recycling we can ensure that the materials in a product are recovered as best as possible. Applying recovered ('recycled') materials in new products is also an important part of design for recycling. An inspiring example in the field of textiles is the use of 100% recycled yarn by Interface, a global manufacturer of carpets, in their Net Effect tiles (Pauw 2015). The nylon of these tiles is sourced by collecting discarded fishing nets from oceans and beaches. In addition to the use of recycled nylon, a random pattern is applied in a smart way, hiding quality variations in the nylon. Further, Interface started applying polyvinylbutyral, obtained from recycled car windows, to replace the latex in the precoat that takes care of adhering the yarn to the tile backing. This decreases the environmental load of the precoat by 80%.

Product and part recovery: repair, refurbishment, remanufacturing and parts harvesting

To maintain or recover functionality at the end of the life cycle of a product, i.e. to enable a subsequent life cycle, products can be reused, repaired, refurbished or remanufactured. If complete products cannot be recovered, it might be worthwhile to harvest some of their parts and refurbish or remanufacture them (Figure 6). Repair, refurbishment and remanufacture are differentiated according to the quality of the recovered product relative to the original. In the case of remanufacturing, the product gets an extensive overhaul and is brought back at least to

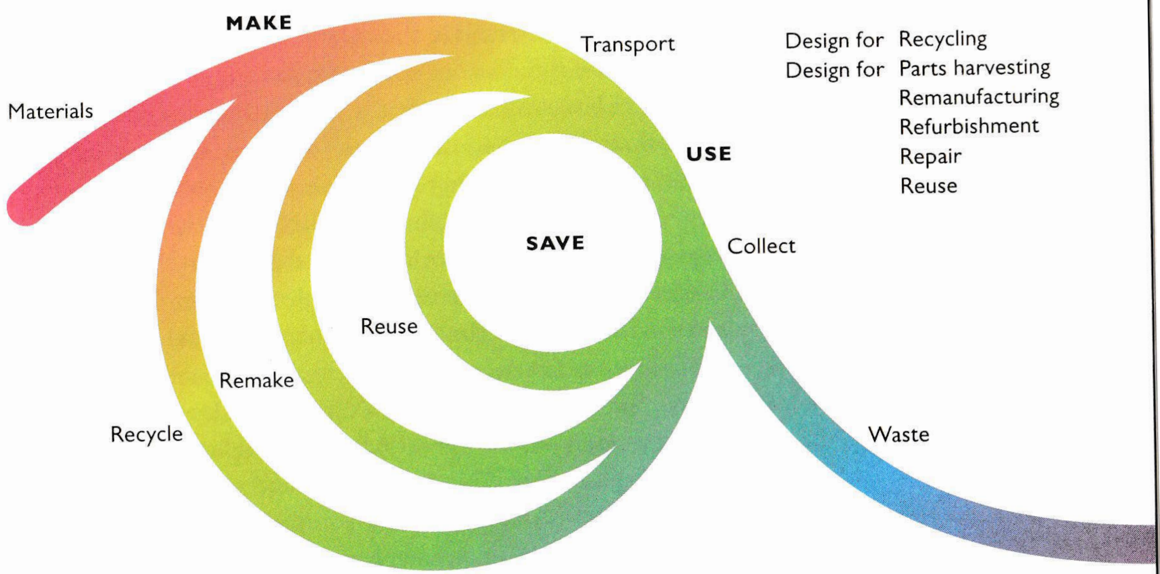

Figure 6. The product life cycle for products in a circular economy. The emphasis is on keeping products and materials in use through recovery operations.

Original Equipment Manufacturer (OEM) specification (Hollander 2017). In the case of repair and refurbishing, the process is less comprehensive and the condition of the repaired or refurbished product may be inferior to the original specification (Gray 2007). The handling and treatment of a product at the end of a life cycle is to a large extent similar, although repair is usually a limited operation (e.g. fixing a flat tyre or replacing a broken zipper) whereas refurbishment and remanufacturing require more elaborate processes, involving operations like disassembly, cleaning, inspection, diagnosis, testing, upgrading, aesthetic touch-ups and reassembly. Design should therefore optimally allow for such operations.

Repair

Design for repair tends to focus on self-repair by product owners. Typical design for repair criteria are the use of standard, universally applicable components and the use of standard interfaces to enable the quick replacement of broken parts with a minimum number of tools. Other criteria include the provision of (free) repair instructions and the design of 'use cues' in the product that guide repair. Also, it is considered important that the most fragile parts (liable to break or wear down) are easy to access and handle. However, this design for repair approach strongly focuses on self-repair and neglects serviced repairs. The comparison between smartphones from Fairphone and Apple is interesting in this respect. The Fairphone II (a smartphone designed by a company in the Netherlands) is built in a modular way, with a relatively low level of integration. Easy accessibility and facile replacement of all modules is enabled. This allows easy repair and even upgrading of parts by the user. Apple's iPhone X on the other hand has an integrated design: the interior of the smartphone is almost inaccessible unless special actions with specific equipment are carried out. Even if the interior of the phone is accessed, the way in which modules are connected make this product very difficult to repair by ordinary users. However, repair is still straightforward for an expert repair service, the advantage for the company being that the quality of repairs can be guaranteed. Also, the reliability and durability of the product is related to the quality of its construction. From a sustainability point of view this points to an interesting trade-off between durability and reliability as such, and ease of repair.

From a circular economy perspective both approaches can be seen as different routes towards a longer than average product lifetime. Which approach is preferable from a sustainability point of view? Interestingly, both approaches can be justified. It will depend on the business model as well as on the behaviour of the user. Fairphone has chosen to operate in an open system, where the input and active participation of others is crucial. Fairphone has used design explicitly to enable its users to take actions that are necessary to recover the product. This also means that its

customers need to act accordingly. This is a model that will w with sufficiently motivated users. Apple on the other hand tar who desire a high-end phone which is built for performance. opted to operate in a fairly closed and controlled system. Th dependent on Apple or qualified repair shops to restore the pr fails. Such a controlled closed system can be a perfectly valid also from a sustainability perspective, but the model only wo the manufacturer takes full responsibility for recovery of the and enables the user easy and affordable access to repair. To su two different design approaches to repair which can both be when it comes to product lifetime extension. But to be succes both need to explicitly take into account the opportunities for at the end-of-life of the product, not only from a technolog spective, but also involving business model and user involveme

Refurbishment, remanufacturing and part harvesting

Refurbishment, remanufacturing and parts harvesting close th loop at the level of the manufacturer. The success of these strategies depends on the long-term vision of and the resp taken by manufacturers. By their nature these operations req sight and planning regarding business perspective and deve in product design. Offering products in multiple use cycles succeed if these recovery strategies are an integrated part of th model and product design.

Refurbishment and remanufacturing imply that used pro collected, involving reverse logistics, and subsequent disasse resulting parts and modules are then cleaned, inspected, an essary repaired, revised, and sometimes adapted, replaced or This is followed by the re-assembly and testing of the system design should facilitate the refurbishment and remanufacturin including component durability, ease of disassembly and r operations, accessibility, and cleaning, but also reverse log

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From a circular economy perspective both approaches can be seen as different routes towards a longer than average product lifetime. Which approach is preferable from a sustainability point of view? Interestingly, both approaches can be justified. It will depend on the business model as well as on the behaviour of the user. Fairphone has chosen to operate in an open system, where the input and active participation of others is crucial. Fairphone has used design explicitly to enable its users to take actions that are necessary to recover the product. This also means that its customers need to act accordingly. This is a model that will work well with sufficiently motivated users. Apple on the other hand targets users who desire a high-end phone which is built for performance. Apple has opted to operate in a fairly closed and controlled system. The user is dependent on Apple or qualified repair shops to restore the product if it fails. Such a controlled closed system can be a perfectly valid approach, also from a sustainability perspective, but the model only works when the manufacturer takes full responsibility for recovery of the product and enables the user easy and affordable access to repair. To summarize, two different design approaches to repair which can both be successful when it comes to product lifetime extension. But to be successful, they both need to explicitly take into account the opportunities for recovery at the end-of-life of the product, not only from a technological perspective, but also involving business model and user involvement.

Refurbishment, remanufacturing and part harvesting

Refurbishment, remanufacturing and parts harvesting close the product loop at the level of the manufacturer. The success of these recovery strategies depends on the long-term vision of and the responsibility taken by manufacturers. By their nature these operations require foresight and planning regarding business perspective and developments in product design. Offering products in multiple use cycles will only succeed if these recovery strategies are an integrated part of the business model and product design.

Refurbishment and remanufacturing imply that used products are collected, involving reverse logistics, and subsequent disassembly. The resulting parts and modules are then cleaned, inspected, and if necessary repaired, revised, and sometimes adapted, replaced or upgraded. This is followed by the re-assembly and testing of the system. Product design should facilitate the refurbishment and remanufacturing process, including component durability, ease of disassembly and reassembly operations, accessibility, and cleaning, but also reverse logistics and marketing (Shu 1999; Nasr 2006). Most of these concepts are familiar in common product design but are now applied with a different aim. As an example, modularization and platform design are commonly intended to improve production efficiency and lower costs, for example enabling an extended product family while building upon a limited set of modules. Although future generations might use the same set of modules, planning is usually limited to a 3 to 5-year timeframe. In remanufacturing the focus will change to efficient disassembly and process organization, where a time horizon of at least 10–15 years should be considered.

Neopost, for example, designs and manufactures a variety of products to facilitate mail management, such as franking machines. In 2012, the company undertook an ambitious remanufacturing strategy. Instead of selling their franking machines they now offer them as a service through lease contracts. The products are designed with a time horizon of 10 years, in order to facilitate two commercial life cycles of five years. Neopost needed to think about the upgradeability of the electronic motherboard in the current range. The functional requirement is 32MB whereas the next generation is likely to be 64MB, so to provide the possibility to rework the Printed Circuit Board Assembly (PCBA) the design team opted for a 64MB at the outset. This shows how the designers had to think ahead and plan for the multiple use cycles of the franking machine (ERN 2018).

While remanufacturing is typically controlled by OEMs or OEM-licensed third parties, refurbishment is more often done by unlicensed third parties, the so-called Gap Exploiters: entrepreneurs who exploit leftover lifetime value in products (Hollander 2016). Refurbishment of smartphones, for instance, is a rapidly growing market. In 2017, the global market for refurbished smartphones grew 13%, whereas the market for new smartphones only grew by 3% (Kang, 2018). The refurbished phone market is now 10% of the total global smartphone market, with refurbished phones available in many different grades and qualities and advertised with poetic qualifiers such as 'reborn,' 'pre-loved,' or 'certified pre-owned.' This is a marker of the success of the

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circular economy but it also requires vigilance, because consumers are increasingly confused with the different quality indicators leaving open a risk of back-lash if poorly refurbished devices flood the market. The example shows again that OEMs (and designers) need to plan for the future use-cycles of their products, in particular those with a high resale value, such as smartphones. They need to recognize the possibility that their devices may be repaired and refurbished by unlicensed third parties or consumers and plan their design and business model accordingly.

Parts harvesting is the retrieval of components, modules or parts from obsolete products with the purpose of using them as spares, parts for servicing, maintenance and repair. From the perspective of the parts supplier, the harvesting and revision of parts can be considered as equivalent to remanufacturing. This is quite common in the automotive industry, for ICT equipment and professional machinery (ranging from heavy duty machinery to medical equipment). Parts harvesting is often closely connected to refurbishment and remanufacturing, with which it has most of the associated design principles in common.

Product recovery strategies are mainly observed in the case of capital-intensive business-to-business (B2B) products, like medical scanners and heavy machinery. The automotive industry provides an interesting example, where remanufactured parts purchased at the aftermarket often replace defective parts. After repair, the replaced part is returned to a remanufacturing plant against a financial incentive. Although in this example, the harvesting and subsequent remanufacturing of parts takes place in a B2B environment, the operations concern a consumer product.

Conclusion

Design for CE puts attention for product life extension and recovery firmly on the agenda, with some surprising new insights for design. One of these new insights is the need for a long-time horizon, beyond product use and towards multiple use cycles, i.e. foresight. This needs to be reflected upon in the strategic stages of the product innovation process and may eventually change the role of design to become more strategic. Related to this is the need for designers to engage with business models. Repair and refurbishment examples show that the meaning and implications of these processes can be different in different contexts. Basic aspects here are related to ownership of the product, the responsibility for the recovery processes, and execution of the recovery processes. Designers need to be aware of these aspects and take them into account in the early stages of product design. Lastly, design for recycling needs to mature. Recycling technology is rapidly developing, and designers cannot afford to be 'out of the loop.'

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