BEST DESIGN PRACTICES

ResCoM report D3.2

IDEAL&CO Explore, DUT

with input from Eurostep, INSEAD, and KTH

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1. Introduction

The majority of the current design tools that consider End of Life (EOL) of products at the design phase are developed mainly for products with a single use life. Therefore, the design efforts are limited to part recovery and separation to remove toxic substances or separating similar materials before shredding or land filling. These tools do not provide support if the products are recovered for putting back into the market through remanufacturing. Environmentally and economically sustainable material recovery (through recycling) are the main objectives of these tools; as a result, destructive disassembly, which is exactly opposite to the requirements of remanufacturing is often permitted. Modular design, again a requirement in case of remanufacturing, suffers from similar problems with some additional challenges. If the priority is given to recyclability, other module drivers get affected and the modularization becomes complex. Furthermore, there is still a serious lack of design methodologies which take into account the business, engineering and sustainability objectives in an integrated way. Nevertheless, there are best practices in industry that have taken first steps in the actual closing of product systems, some with products going through multiple lifecycles (# ref Rashid et al.).

This report presents the results of the analysis of best practices from industry in closed loop product system design, linking to relevant design strategies, frameworks, methods, tools, and standards. It provides an overview of the state-of-the-art in current closed-loop design that can contribute to the ResCoM methodology, identifying key methodological gaps and critical success factors for the development of the methodology. This report will serve as a major source of input to the work necessary for deliverable D3.3: Report on the ResCoM design methodology for the four case studies.

2. Research aim & set-up

The aim of this study is to make a state-of-the-art inventory of the best design strategies, frameworks, methods and tools that can contribute to a dedicated multiple lifecycle design methodology, and to define methodological gaps such as what key issues are not yet addressed, and what needs to be adapted to meet the requirements of multi-lifecycle design. This exercise may also lead to additional requirements that will be fed into the company-specific requirements developed in WP2.

2.1 ResCoM design terminology & design scenarios

Before translating the research aim into tangible research questions, first the main terms used in this work-package are introduced and defined.

ResCoM aims to contribute to a dedicated multiple lifecycle **design methodology**. The term design methodology is used in this research in the meaning of: a body of knowledge comprising the principles, guidelines, best practices, methods, and processes relating to the discipline of product design (based on Gabriel-Petit 2010). **Methodology** thus refers to the body of methods and principles particular to a branch of knowledge. Methodology has a different meaning from the term **method**, which refers to a specific “procedure, especially a regular and systematic way of accomplishing something” or “the procedures and techniques characteristic of a particular discipline or field of knowledge….” (The American Heritage Dictionary of the English Language). Explained more pragmatically, “a method is a way of doing things; a methodology is a set or system of methods.” (Dictionary.com). The methodology comprises of a coherent set of possible design principles, best practices, methods etc. that support designers in contributing to a closed-loop product system, with design for multiple lifecycles as key approach.

The terms closed-loop product system and design for multiple-lifecycles have already been defined within this project (D2.2):
A **closed loop product system** is an industrial system in which products, components and materials are consistently reused rather than discarded as waste (landfilled, incinerated or other terminal options) (D2.2). Design for **multiple lifecycles** is an approach for product design aimed at retaining EOL products or components and putting them back into the value chain through remanufacturing or reuse, as illustrated in Figure 1 (DOW).

ResCoM distinguishes two fundamentally different mechanisms when addressing resource flows: slowing resource flows and closing resource flows (see D2.2). This resulted in two related definitions within closed-loop design:
1) Slowing resource loops: the goal is to extend the utilisation period of products. This can be done through the design of long-life goods and product-life extension (i.e. service loops to extend a product’s life, for instance through maintenance, repair), and through design for loops to extend a product’s life, for instance through maintenance, repair).
2) Closing resource loops: the goal is to close the loop between post-use and production. This is usually referred to as recycling. The closing of resource loops can be take place at different parts of the value chain, as illustrated in the EMF diagram in Figure 2.

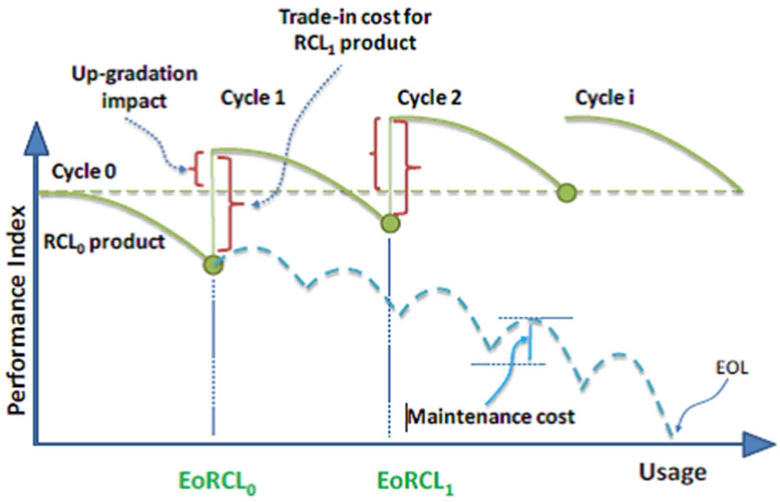

Figure 1: Comparison of the conventional lifecycle (blue- dotted curves) and the ResCoM lifecycle (green-solid curves).

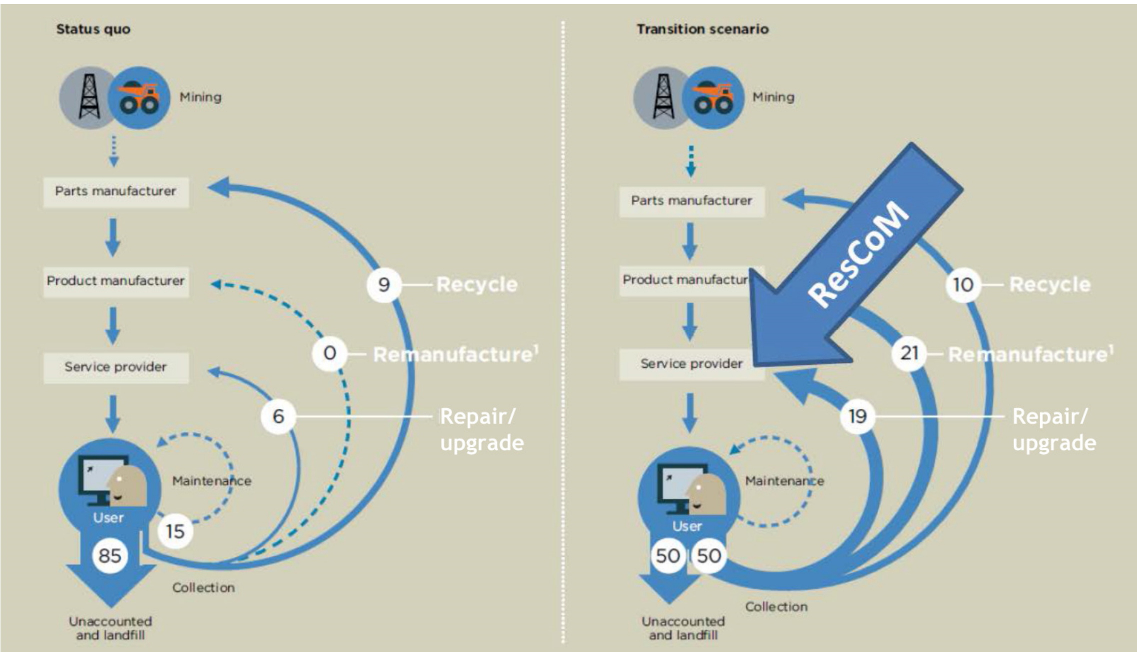

Figure 2: EMF diagram, adapted to ResCom terminology from D2.2 (“reuse” changed into “repair/ upgrade”).

For analysing the best practices, three design scenarios are distinguished, illustrated in Figure 3, that combine the two mechanisms for closing the loop with the different cycles from Figure 2. This classification helps to determine which type of loop and what cycles have been addressed in the design processes of the best practices.

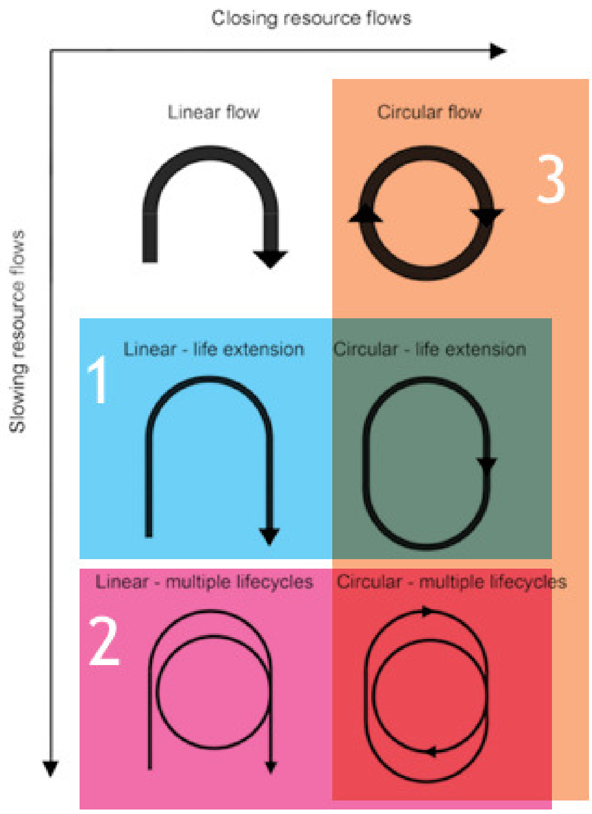

Figure 3: Resource flows and design scenarios 1-3.

Design scenarios:
1. **Product life extension**. When a product is designed for life extension, it allows for repair or upgrading. After being used, the service provider repairs and/or upgrades the product to make it fit for another use life. The product is then used again, not necessarily by the same user, with a warranty that is typically less than that of a new product's warranty. Including product life extension as a design scenario implies that the product is designed upfront with specific possibilities for repair and upgrading, as well as high reliability, and physical and emotional durability.

2. **Remanufacturing**. When a product is designed to be remanufactured, specific components of the product are designed to be used again in a subsequent product life. After being used, possibly several times and for as long as designed for under scenario 1, the product returns to the manufacturer (or a third party licensed by the manufacturer). The manufacturer separates the product into parts and sub-assemblies, which are checked and then reconditioned or replaced. From a batch of those parts and sub-assemblies, new products are assembled in a series or mass production setup. These remanufactured products have at least the same performance and typically the same warranty as the original products. In this design scenario, the product is intended for this remanufacture loop and corresponding production setup, having predetermined disassembly solutions and modularity that allows components to be replaced with newly made or improved ones.

3. **Closed loop recycling**. In a design scenario aimed at closed loop recycling, the design allows full recycling of the materials used in the product. After the last use life, not necessarily the first one if the product was reused or remanufactured, the product enters into a recycling

infrastructure. This can be at the manufacturer, a supplier of the manufacturer or an outside party that supplies recycled materials. The product is separated into materials that are either pure or compatible in their composition. This may also happen within a remanufacturing process, to components that cannot be reused. The separated materials undergo a process that returns them to at least the same quality of that material from virgin production. This process may be primary recycling or tertiary recycling. Secondary recycling (downcycling) and biodegradation are excluded in closed loop recycling unless there is a subsequent stage where the downcycled or degraded materials are transformed into virgin-like material again. In this design scenario, the product is optimized by design for a chosen recycling infrastructure and separation device. If the product cannot be recycled in its entirety, problematic parts are designed for easy separation and subsequent processing.

In addition to scenarios for ‘closing the loop’, the circular economy considers the element of regeneration: the realisation of regenerative cycles that rebuild or strengthen economic, social and natural capital. As such, this scenario does not address a singular value chain component nor does it necessarily address the flow of material resources. Regeneration can address any aspect of the (eco)system of which the product system is part. Our analysis showed that only very few cases address the design for regenerative cycles, cases of which the product type was not assessed as relevant for the ResCoM industry partners. This design approach is applied by a highly limited number of frontrunners, such as Interface and Desso (see also Appendix 1). As a consequence, we have excluded the design for regenerative cycles as a separate design scenario.

2.2 Research design

This section describes the different aspects of the research design: the research questions & approach (2.2.1), the research scope and focus (2.2.2), the procedure for the selection of best practices (2.2.3), and the method for data analysis (2.2.4).

2.2.1 Research questions & research approach

To reach the aim of this work-package, the research will have to answer the following research questions:

1) What design engineering approaches, methods, and tools are currently used by the industry partners, where the ResCoM design methodology is to be implemented?
2) What are the key design drivers and barriers for implementing ResCoM found within the industry cases?
3) Which cases provide best practices for the implementation of closed loop design for multiple lifecycle products?
4) What design methodology is applied in these best practices that can contribute to the ResCoM methodology (such as design strategies, methods, and tools)?
5) What key methodological gaps need to be closed to go from current design practices to ideal ResCoM cases?
6) Which critical success factors can be identified from the current and best practices for the development of the ResCoM methodology?

To answer these questions, both the industry cases included in the ResCoM project and best practices from other companies are reviewed against the ResCoM framework, as illustrated in Figure 4.

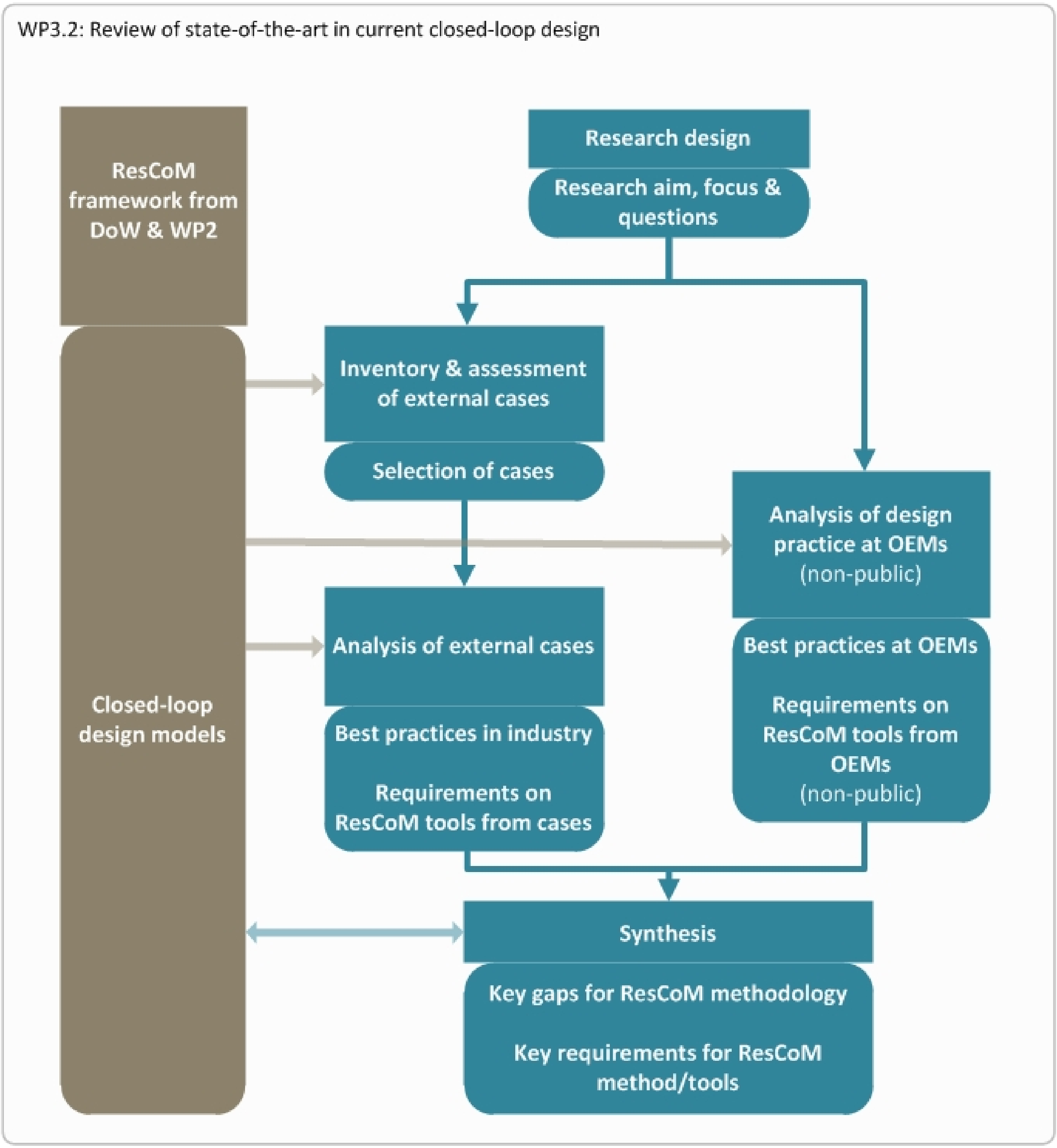

Figure 4: Research design in WP3.2.

2.2.2 Scope and focus

Research scope: the product design process

This study looks at the design phase of product development. This phase generally begins with a project brief and ends when the design is determined in sufficient detail to start production. The project brief follows from strategic decisions and determines the main goals of the design phase, such as production volumes, market segment, cost price and functionality. For circular product design, these main goals would also include ResCoM goals such as a number of life cycles or recycling criteria. As a consequence, this study includes an analysis of the strategic phase prior to the project brief, but only where it concerns ResCoM oriented goals.

When the design is detailed for production, it has been designed for the production means at hand and, in a ResCoM case, for the available or planned means for recycling, remanufacture and life extension. So, even as the design phase excludes the production and EOL phases, these latter phases are to be taken into account within the design phase.

Consequently, the scope of this study is: the strategic ResCoM decisions leading up to the project brief, the activities in the different design phases, including those aspects of the production and EOL phases that are vital for a ResCoM design.

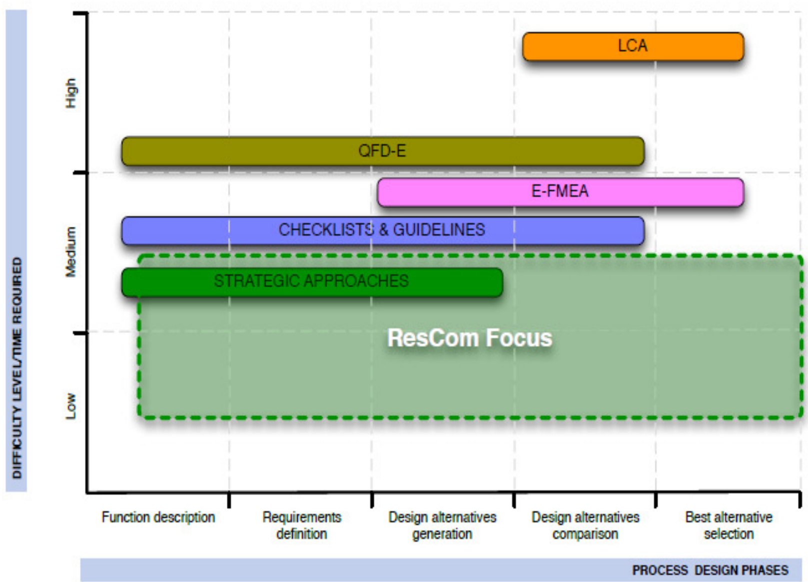

Figure 5: ResCoM focus in terms of the difficulty level/ time requirements of approaches, methods and tools for integrating environmental requirements in the design process (DOW).

Research focus: industrial best practices

This study focuses on best practices that have succeeded in slowing and/or closing the loop. Though valuable, more generic design methods and tools such as those covered within traditional eco-efficiency approaches are not included in this analysis. Furthermore, following the ResCoM objectives, the research will focus on industrial best-practices, providing insights geared towards the needs of the industrial partners as well as future users of the ResCom methodology, including SMEs. Consequently, methods and tools that have a high complexity, which render them unfit for use in the industrial environment, in particular for SMEs, will not be included in the analysis (see Figure 5). Standards in Design for Sustainability, described in D2.2, do not address design methods or design methodology and have therefore not been included in this review.

2.2.3 Procedure for the selection of best practices

To select best practices for the ResCoM design methodology, first an overview was compiled of cases that may contain best practices, addressing each of the design scenarios described in section 2.1. Each ResCoM partner has been asked to provide cases, to ensure coverage of all ResCoM pillars in the overview. Table 1 provides the list of best design practices in commercial industry cases that address at least one of the design scenarios described in Section 2.1.

Best practices		Closed loop design scenarios applied		
Manufacturer (in alphabetical order)	Product	Product life extension	Remanufacturing	Closed loop recycling
BAE Systems	GCS vehicles			
BMW	Cars			
Caterpillar	Heavy machinery (all)			
Desso	Airmaster carpet tile			
Ecosmart	Smartbin resource collection system			
Fairphone	Fairphone mobile phone			
Full Circle Design	Plenic presentation system			
GreenTom	Upp stroller			
Herman Miller	Mirra office chair			
Interface	Net Effect random carpet tile with Tactiles			
Kingfisher	Carrierpac and Longspac transport packaging			
Kodak	Single use analogue cameras			
Kongsberg	Protech Systems / combat vehicles			
Maille	Mustard packaging			
Miele + Wasbundles	Pay per wash washing machines			
Mud jeans	Lease Jeans			
Océ(Canon)	Printers			
Philips	Pay-per-Lux lighting system (Washington)			
Philips	SlimStyle LED lamp			
Pley	Lego sets rental service			
Roetz-bikes	'Public-transport' bicycle Recycle			
Robert Bosch	Power tool			
Scania	Trucks			
Splosh	Home cleaning products (all)			
Xerox	Asset management program for printing equipment			

Table 1: overview of commercial best practices related to closed loop product design. Green cells mark the design scenarios that have been applied in a case.

From this overview, a selection of best practices is made in Section 4.1 using five criteria:

1. The case is a key example for at least one and preferably more of the design scenarios: life extension, remanufacturing, or closed-loop recycling.
2. The case is relevant for at least one and preferably more of the ResCoM industry partners: address the design-related barriers and opportunities of the OEMs. These barriers and opportunities are identified and described in Chapter 3.
3. Sufficient data on the design is available on the case.
4. Preferably, the case addresses at least two and preferably more of the ResCoM pillars: next to closed loop design also closed loop business models, supply chains, and/or PLM technology for closed loop product systems.
5. From the cases that meet criteria, those are selected that either score highest on criteria 1-4 or address design scenarios, OEM-specific topics and ResCoM pillars not addressed by higher-scoring cases.

2.2.4 Method for data analysis

Following the aim of the research, the analysis of the current and best practices will focus on the design strategies, methods, tools etc. applied. The analysis will be structured according to the ResCoM design scenarios described in section 2.1, that are based on the different ‘cycles’ within closed-loop product systems, as shown in Figure 2. Data is collected from literature, interview sessions at the industry partners and a questionnaire at the first consortium meeting.

3. Current design practices (non-public)

This chapter analyses the current design practices at the OEMs involved in the ResCoM project, to answer the first two research questions.

The content of this chapter is confidential and therefore not included in this public deliverable.

Cases (in alphabetical order)	Best practice in design for			Best practice for		
	life extension	remanu-facturing	closed-loop rec.	busin. models	supply chain	(PLM) Technology
1. BAE Systems - GCS Vehicles						
2. Caterpillar - Heavy machinery*						
3. FCD - Plenic presentation system*						
4. Herman Miller - Mirra office chair*						
5. Miele+Wasbundles - Pay per wash						
6. Philips - SlimStyle LED lamp*						
7. Roetz-bikes – 'Public transport' bicycle						
8. Scania - Trucks						
9. Xerox - Printers						

*Table 8: selected best practices. Cases marked * were also selected in the analysis of closed loop product requirements (see D2.2).*

Best practice	Practice	Not applied/no data

4. Best design practices

This chapter presents best design practices in view of the ResCoM framework. In section 4.1, the selection of best practices in closed loop design is described. The following section analyses each of the selected best practices according to the different ResCoM design models: design for product life extension, design for remanufacturing, and design for closed-loop recycling. Emerging practices in the development of restorative and regenerative design are described in section 4.3.

4.1 Selection of best design practices

Based on the overview of best practices and selection procedure provided in section 2.2, and the ResCoM barriers and opportunities identified in Chapter 3, nine best practices for the ResCoM design methodology have been selected. Table 8 shows the selected cases, with the ResCoM design scenarios and pillars each of these cases address.

RQ3: Which cases provide best practices for the implementation of closed loop design for multiple lifecycle products?

4.2 Review of best design practices

This section describes the results from the review of the eight selected best design practices.

4.2.1 BAE Systems – Combat Vehicles

BAE Systems (British Aerospace Engineering Systems), division Combat Vehicles develops combat vehicles designed for the military to operate in remote and harsh conditions. Vehicle types include battle tanks, infantry fighting vehicles, armoured engineer vehicles, armoured all-terrain vehicles and military bridging vehicles. Specific products include the Challenger 2 main battle tank and the CV90 infantry fighting vehicle family. The vehicles can be characterised as high-cost, high-complexity products for which reliability and durability are key design parameters.

Figure 7: Example of a BAE combat vehicle (Credit BAE Systems).

Project goal & business case

The business case for combat vehicles are dissimilar from those of the industry partners involved in ResCoM. Investment costs are generally much higher (>> 1mln euro/vehicle), while at the same time lifecycle costs are much more important to its customers, as these vastly exceed the initial investment . Much effort, both at BAE as well as the customer side, is invested in prediction and optimization of the lifecycle costs for different usage scenarios. The system that is optimized for high availability and low lifecycle costs includes both the vehicle system itself and its support system. Nevertheless, also BAE Systems has competitors in the market, and they have to bid to obtain assignments. This case could be viewed as an example of a market situation in which resource scarcity dominates over investment costs.

BAE Systems distinguishes between 'Customer projects' and 'Private Venture Projects'. In the first case a customer is heavily involved both as the source of requirements and as the funding partner while in the latter case BAE is financing the project itself.
Vehicles are tailored on the basis of customer requirements, and in general 'availability' of the vehicle is of crucial importance. Availability differs to some extent from 'reliability' as defined within ResCoM: when designing for availability, parts that can be replaced easily (in terms of time, cost, and presence of parts) can have less strict requirements on reliability and durability.

Resource flows

With respect to resource conservation, the vehicles can be considered a best practice in slowing resources flows by lifetime extension and the reuse of parts over multiple lifecycles (Figure 8). The company has developed a take-back system to ensure reuse of parts. BAE has many large projects to replace units on component level or remanufacturing of (complete) vehicles at specific points in the life-cycle of the vehicles. Materials recycling is ascertained as part of the BAE process, but no specific data was found on the inclusion of recycling in the design process.

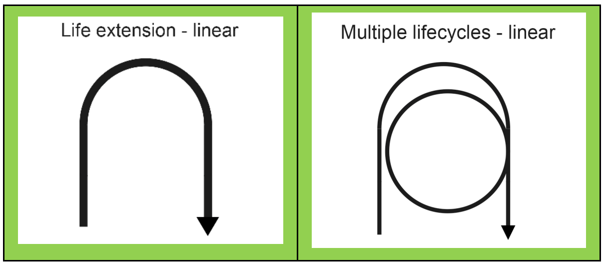

Figure 8: Resource flow categories for Combat Vehicles.

Design approach: system engineering

BAE Systems develops new vehicles using a systems approach with multiple levels:

- systems engineering, where requirements, functions, system objects (objects at systems down to component level), and platforms are managed
- product development & design, where the subsystems, and mechanical, electrical, and software design are developed
- manufacturing system design, including process routing and resources
- support system design, and
- product support.

On top of that, also a 'System of System' is defined, linking the usage of the vehicle with systems for equipment support, supply support, training, etc. This information is also required in the design phase, because the availability (or non-availability) of warehouses at the operating location influence the design of the subsystems. To have maximum availability of the vehicle, subsystems or modules are designed for replacement at either the battlefield, the line, or a specialised workshop.

BAE systems work with platform based designs. Each platform contains 'independent' sub-systems such as propulsion, vehicle body, electronics, and weapon systems, see Figure 9. Each of the sub-systems are continuously improved, and the vehicles are tailored to meet specific customer requirements. Systems that are prone to fast technical development are designed for remanufacturing, with specific efforts directed towards interface design. The company's efforts on design for environmental sustainability focus on compliance and lifetime carbon footprint. However, for each sub-system, an end-of-life strategy is developed describing the handling of components at end-of-life.

In the design process, requirements are established 'top-down' from platform level, sub-system level, to component level. They are formulated in terms of functional capabilities, independent of the solutions.

To handle system complexity, extensive support systems are in place for PLM (Product Lifecycle Management), ERP (Enterprise Resource Planning), SCM (Supply Chain Management) and CRM (Customer Relationship Management). For the technical product data for instance, for each of the product's items, data is collected of the module, part, and interface linked to the item, including the version of each item, module, part, and interface, as well as the definition of context of each (describing specific domain purposes). 'Interfaces' refer both to physical interfaces (geometry), material flows, energy transfers, and information transfers.

System Engineering

In system engineering, the emphasis is placed on a top-down, integrated, life-cycle approach to system design and development. The basic process and phases closely resemble a typical product development approach, but is executed at a systems level, with specific consideration of the relations between the different system components (including equipment, software, operating personnel, operating context, maintenance and support). Requirements analysis and Functional analysis play a key role in the development process.

Characteristics:
> Top-down (and bottom-up) integrated approach
> Addresses the system within a higher-level system of systems context
> Covers the entire system life cycle (described as a linear process)
> Considers the influence of decisions across development phases.

Design strategies:
> Design for Reliability, Maintainability, Usability, Supportability, Producability and Disposability, and Design for Affordability (life-cycle costing).

Examples of design methods & tools:
> Design review checklist (generic)
> Different analytical tools for failure modes, reliability, maintenance, repair, design

Box 1: System Engineering. (Blanchard 2014, Blanchard et al. 1990, Lightsey 2001).

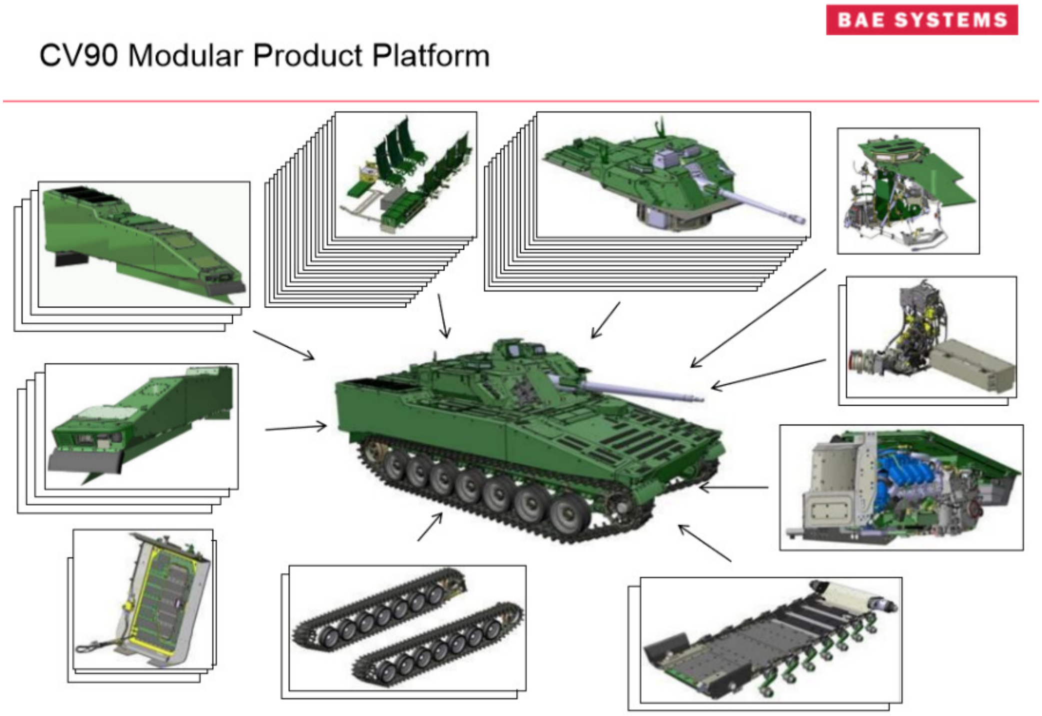

Figure 9: example of the product platform of one of BAE's products (credit BAE Systems).

Insights from this case

This best practice illuminates how, once the business case has been established, even highly complex systems can be designed for life extension and reuse of components. In more detail, the following insights were obtained:

- In view of ResCoM, the design approach used was system engineering.
- This approach aided BAE Systems to manage the development of the platform based design
- Servicing of the product is developed in parallel to system & product development.
- PLM systems aid the development team in ensuring exchange of differed modules for different variants for different clients or changes throughout time.
- The basic build-up of the PLM-system seems feasible to also accommodate, in a simplified form, products with lower complexity.

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4.2.2 Caterpillar - Heavy machinery

Caterpillar is a manufacturer of heavy machinery, founded in 1925. In addition to a large portfolio of trucks, dozers, conveyer systems, mining equipment and the like under the brand name CAT, the company offers remanufactured products and remanufacturing services under the brand name CAT REMAN. The company acquired engine remanufacturing companies in the US and UK in 2004 (Caterpillar 2005), a French automotive part remanufacturing company in 2007 (Caterpillar 2008a) and in 2008 bought a Brazilian railroad equipment manufacturer (Caterpillar 2009) and an American transmission remanufacturer (Caterpillar 2008b). In 2014, CAT REMAN has 17 dedicated remanufacturing facilities around the world (Peoriamagazines.com 2008). With these assets and a global infrastructure, CAT REMAN operations are primarily focused on the remanufacture of Cat engines and components and rail related products (Caterpillar 2013).

Goal & business case
The fact that the remanufacturing facilities operated as independent businesses before their merge into CAT REMAN indicates that a business case for the remanufacture of engines and rail products was already established before Caterpillar started remanufacturing. Rail related products are standardised because of the compatibility requirements for trains. Engines are also highly standardised. The intricate cast engine block, tightly toleranced cylinders, violent forces inside the combustion chamber and the long use life that is demanded, correspond to high development costs which in turn means that engines are used across various vehicles. The high embodied value of engines also makes it worthwhile to spend labour on thorough engine revisions.

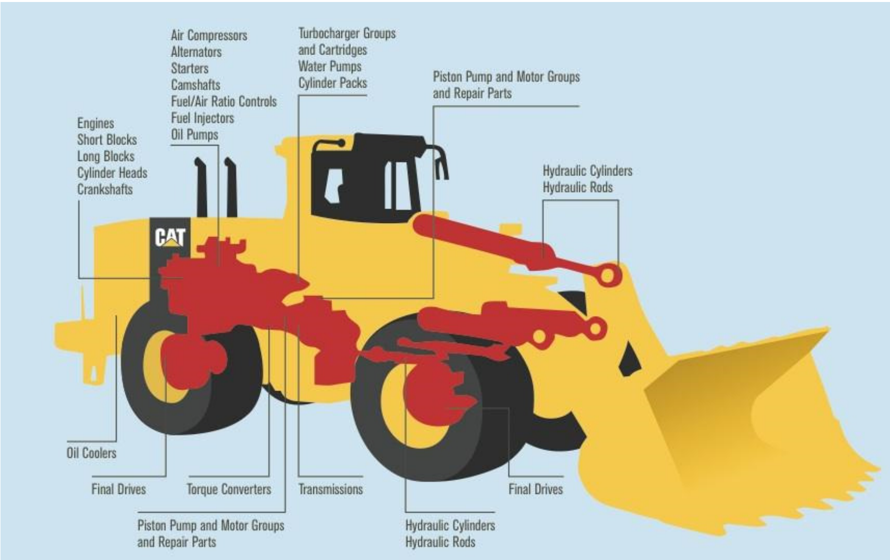

Figure 10: Example of product structure (Credit: Caterpillar).

Prerequisites for Design for Remanufacture
Only engines and main components like cylinders (shown in figure 10) are remanufactured at CAT REMAN. This is because these components are eligible for remanufacturing following the criteria formulated by Andreu (1995):

- The product is durable in nature
- It has failed functionally

- The product is able to be disassembled and restored to its original condition
- The retained value-added in the cores is high relative to both the original cost and market value – it is cost-effective to remanufacture
- The product is standardized and factory-built rather than assembled in the field
- A ready and continuous supply of cores is available
- The product technology is stable, and
- The process technology is stable.

Some of these prerequisites depend on the design, which can be made to be more durable, easy to disassemble, restorable, standardized and factory-built.

The value retention is more difficult to influence within the confines of a competitive product. Body panels for instance have low added value compared to the sheet metal they are made from, and in most cases it will not be cost-effective to remanufacture them. Spending more money on the production of such panels by adding complexity or material would not increase their market value. But when a component has a value that can be better retained by spending more on its production, as in the example by Scott below, it may become cost-effective to remanufacture this part.

Figure 11 illustrates the CAT REMAN process. The supply of engines and components (cores), related to the production volumes, return incentives and availability of reverse supply chains is well outside the domain of influence of designers, as are the stability of product and process technology and –we may add- the stability of customer appraisal; if a type of product is sensitive to fashion and whether its product segment is mature.

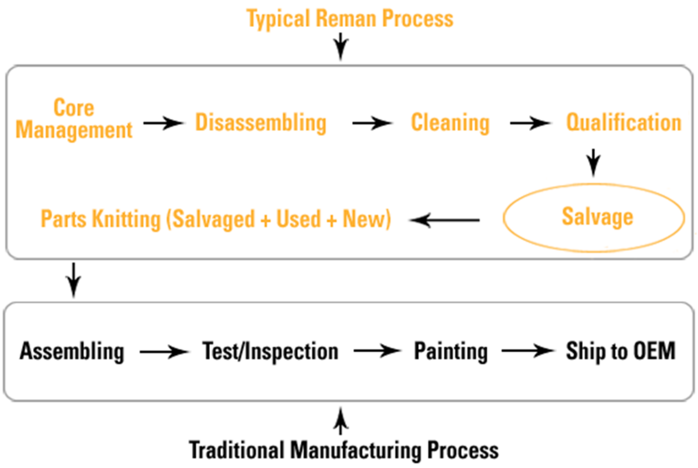

Figure 11: CAT REMAN process map Credit: Caterpillar (2014b).

Resource flows
CAT REMAN receives cores from dealers and these are inspected, cleaned and remanufactured (Caterpillar 2013). These “salvaged” cores are thus returned to as-new condition, including as-new warranty, and are delivered to serve another full service life at a significantly lower cost compared to new products (Caterpillar 2014a) The lower price includes a deposit that is charged to the dealer upon purchase of the remanufactured core and the deposit is returned when the dealer delivers another core within a set timeframe, using a proprietary core management system. The remanufactured cores have a return rate of 93% (Peoriamagazines.com 2008). The percentage of new end-of-life cores entering the reman loop is unknown. The dealers use cores

to extend the life of machinery in which only these components had failed. Not all returned parts can be remanufactured. The parts and materials that are not suitable for remanufacturing are passed on to the company's foundry in Mapleton, Illinois, where they are melted down and recast (Scott, 2008). As the considered products are almost entirely metal and thus recast, this information leads us to believe that this is a closed loop, multiple lifecycle. Also, the remanufactured parts help to extend the life of other products (Figure 12).

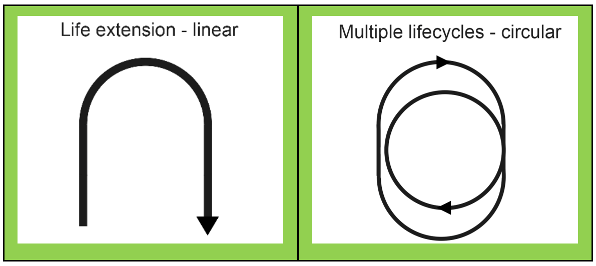

Figure 12: resource flows at CAT REMAN.

The deposit serves as an incentive for dealers to supply used cores at a predictable flow. When a customer needs a new part or a new piece of equipment, he or she is first asked to submit the old one. When an old part is handed in the customer is rewarded with a new part at up to half its full price. If the customer refuses to hand in the old part, the full price is charged (Scott, 2008).

Design approach: Design for Remanufacturing & Design for Upgradeability
Joe Allen, general manager and director of sustainable development for Caterpillar's Reman Division described the Caterpillar design approach as follows: "We need to produce products with multiple life cycles in mind to keep excess waste out of landfills. EPR (Extended Producer Responsibility) drives us to use eco-design—or in our case, 'Design for Reman and Design for Upgradeability.'" (Peoriamagazines.com 2008).

"When using Design for Reman, Caterpillar considers the entire product lifecycle before the design phase even begins, considering such things as type of material used and ease of disassembly for repair, remanufacture, reuse or recycle. By considering the product's remanufacturing potential in the product design phase, Caterpillar engineers have enabled some components to be in circulation for multiple lifecycles." (ibid).

Caterpillar has not disclosed these Design for Remanufacturing and Upgradability methods further. However, the doctoral thesis of Ridley (2013) describes the remanufacturing in detail and refers to Hatcher et al. (2011) who summarised documented design aids (guidelines and metrics, published but not used in industry) for Design for Remanufacturing. They recommend the design concepts listed in Table 9. These concepts align with what we found trough the OEM interviews (see Chapter 3) and strikingly, design for environment -or sustainability tools- are also recommended but not used in practice.

Approach	Author (s)	Format	Style	Key Purpose	Design Stage	Advantages	Disadvantages	Use in Industry
Modularisation	Ishii et al. (1994); Kimura et al. (2001)	Concept	Qual	*Traditional:* improve manufacturing efficiency. *Reman:* ease of disassembly.	Concept develop.	• Familiar concept.	• Not holistic. • No guidance.	Yes
FMEA	Lam et al. (2000); Sherwood and Shu (2000)	Paper/ software	Quant	*Traditional:* prioritise and prevent product failure. *Reman:* reduce waste.	Concept develop, redesign	• Familiar concept. • Lifecycle thinking. • Process oriented.	• Not holistic. • Reliant on reman-OEM feedback. • No guidance.	Yes
Platform design	King and Burgess (2005)	Concept	Qual	*Traditional:* reduce manufacturing costs and retain customer choice. *Reman:* simplify process organisation.	Concept develop.	• Familiar concept. • Lifecycle thinking.	• Not holistic. • No guidance.	Yes
Active disassembly	Chiodo and Ijomah (2009)	Concept	Qual	Efficient disassembly.	Concept develop, detail	• Process oriented.	• Not holistic.	No
Design for environment tools	Pigosso et al. (2009)	Various	Varies	Improve environmental performance.	Various	• Lifecycle thinking.	• Not holistic. • Complex.	No
QFD	Yuksel (2010)	Paper/ software	Quant/ qual	*Traditional:* consider 'voice of the customer' to meet their needs. *Reman:* consider 'voice of the remanufacturer'.	Concept develop.	• Familiar concept. • Process oriented.	• Reliant on reman-OEM feedback.	Yes

Table 9: Summary of recommended design concepts appropriate to Design for Remanufacturing (Hatcher et al. 2013).

Remanufacture influencing design
Cores that undergo inspection at the remanufacture plant uncover valuable insights into the wear and failure mechanisms that parts endure in their use life. Examples of this feedback at Caterpillar are provided by Ridley (2013) and Scott (2008) respectively:

"… one engine remanufactured at the Caterpillar Rushden facility demonstrated unusual wear on one end of the crankshaft when returned for remanufacture. This was investigated during remanufacture and the cause was found to be a feature of the oil pump housing, included to facilitate fitting, that was rubbing on the end of the crankshaft when high engine speed resulted in increased pressure on the accessory drive bringing the two into contact. Feedback given to the OEM resulted in the redesign of the oil pump housing." (Ridley, 2013).

"By designing and producing higher quality parts in advance, Caterpillar has discovered that it can get two or three more lives out of its products. Manufacturing a component with another one-sixteenth inch layer of metal on it may cost more to create, but the company knows that this investment will ultimately yield more profits because the improved product can be remanufactured." (Scott, 2008).

Insights from this case

- In view of ResCoM, the design approaches used were design for remanufacturing and design for upgradeability.
- The entire product life cycle and ease of repair, remanufacture, reuse and recycling are considered before the design phase.
- Designed properties (durability, ease of disassembly, restorability, standardization and value retention) can be used to skew the economic potential for remanufacture.
- Remanufacture can deliver valuable insights used to improve the longevity of newly designed products.

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4.2.3 Full Circle Design - Plenic presentation system

The Plenic presentation system (Figure 13) was developed by Full Circle Design, a small German design firm specialising in the development of closed-loop products. The “Plenic” is a presentation system for fairs and points of sale. Such systems are used to present graphic information, and typically consist of a frame, onto which printed textile fabric is connected with the use of keder (an elastic cord for fixing the textile onto the frame).

Figure 13: Impression of the Plenic closed-loop presentation system by Full Circle Design (Credit FCD).

Project goal & business case
The goal of the project was to develop a modular presentation system that “never becomes waste”. Presentation systems are normally disposed of after only days of use, and contribute to the large amount of waste generated at fairs. Instead of buying and disposing of presentation systems for each event, this design offers a modular frame with printed fabrics that are taken back by the company.

Resource flows
With respect to resource conservation, the Plenic presentation system closes resources flows by combining closed-loop recycling with lifetime extension and the reuse of parts over multiple lifecycles (Figure 14). The company has developed a take-back system to ensure reuse of parts and recycling of parts into new components via selected partners.

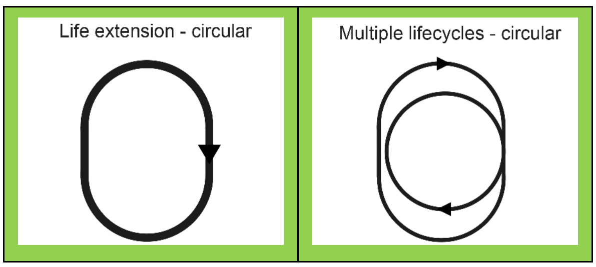

Figure 14: Resource flow categories for Plenic.

De Pauw et.al (2013) report how the use of this 'absolute' design principle challenged the designers to overcome barriers in closing the loop, normally not taken in the design process. Materials that could not be recycled into the same component were replaced by materials that could. This process led to several product and material innovations. For instance, existing printing technology hampered the full recycling of the printed textiles. The designers, together with two selected suppliers, developed a new textile-printing combination that allowed full recycling of the textile. Of the end product, more than 99% or the materials can be recycled. To slow the flow of resources, the designers developed a presentation system with adaptable sizes, by introducing a modular frame (Figure 15). Apart from selling entire systems, the company offers frame modules to adapt the frame, and has designed a take-back system for parts that are disposed of or damaged.

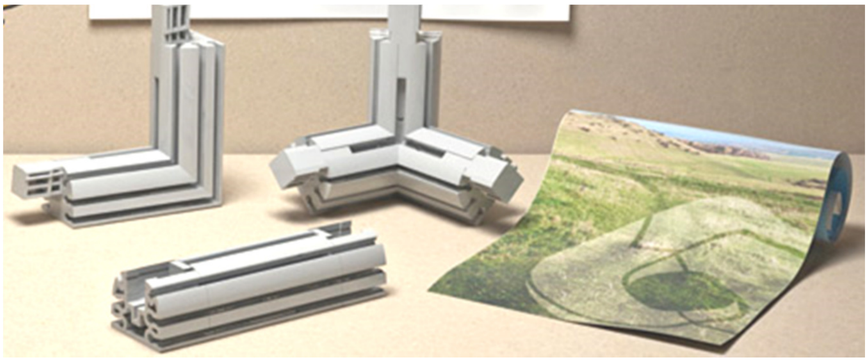

Figure 15: impression of frame modules (Credit FCD).

Design approach: Cradle to Cradle

The product was designed according to the Cradle to Cradle philosophy. Both of the company's designers were formally trained in C2C design, and C2C design principles and tools were used during the development of the product. This philosophy was mainly used for the technical development of the product. For developing the business case, the designers build on their (generic) design expertise. Box 1 provides a brief summary of this design approach and additional references. This case shows how the traditional role of the designers expanded to include the design of 'the loop'.

Insights from this case

- In view of ResCoM, the design approach used was Cradle to Cradle, which specifically aided the designers in a design scenario for closing resource flows.
- In contrast to the previous case, no strict requirements or design guidelines were followed in the design process. The main C2C principle "waste equals food" inspired the project goal, and -aided by specific C2C-tools- guided the designers in developing their concept.
- The two other Cradle to Cradle principles were not explicitly applied. According to De Pauw et al., these principle were not supported with methods or tools, which hindered the designers to integrate the principles in the design process.
- Next to the product, also the material loops and service system were designed.
- In order to close the loop, the designers developed highly context-dependent solutions and partnered with suppliers to overcome barriers in establishing a closed loop.
- Innovative solutions were needed to comply to the 'waste equals food' principle.
- The designers added to the Cradle to Cradle approach a checklist including social sustainability considerations.

- For several phases of the design process, including the development of the business case and Design for Disassembly, the designers could apply their generic design skills and did not require specific closed-loop methods or tools.

Cradle to Cradle Design

Design philosophy:
Strive for ‘Eco-effectiveness’ above Eco-efficiency to create a beneficial instead of a harmful environmental footprint: “doing good instead of ‘less bad’.

Design principles:
> Waste equals food - all resources become resources again (designing out the concept of waste)
> Use current solar income - use only renewable energy resources (from current solar income)
> Celebrate diversity - integrate biodiversity, cultural diversity, and conceptual diversity in design.

Examples of design methods & tools:
> Cradle to Cradle Roadmap (plan intentions in time using milestones)
> Material inventory with ABC-X classification (material cycles healthy for humans and environment)
> Define use in biological and technical cycles
> Define use period
> Design for (dis)assembly.

Box 2: Cradle to Cradle Design. (De Pauw, Karana et al. 2013, based on EPEA 2011, McDonough and Braungart 2002, McDonough, Braungart et al. 2003, Bor, Hansen et al. 2011, Bjørn and Hauschild 2013).

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4.2.4 Herman Miller - Mirra office chair

The design of the Mirra office chair (Figure 16) is a well-known early example of Cradle to Cradle (C2C) design, and one of the few C2C product development cases that have been described in scientific literature.

Figure 16: Photo of the Mirra chair (Credit: Herman Miller).

Multiple teams worked on the design of the Mirra office chair: an external design studio (Studio 7.5), a design for environment team (DfE) at Herman Miller, and also reference is made to the engineers, and other departments (Rossi, Charon et al. 2006, Lee and Bony 2009, Herman Miller 2014). The DfE team was responsible for implementing the Cradle to Cradle aspects.

Resource flows

In terms of resource conservation, the Mirra office chair closes resource flows by using 42% recycled content in manufacturing. Furthermore, it enables closing of resources flows by closed-loop recycling up to 97% of the parts, depending on the recycling infrastructure (Herman Miller 2014). Though other companies offer ‘remanufactured’ Mirra chairs, the company itself is not involved in organising the end-of-life processing of the chairs: “We do not currently have a system in place to take the chair back. But we see down the road that that would definitely be in the picture.” (Metropolis Magazine 2007).

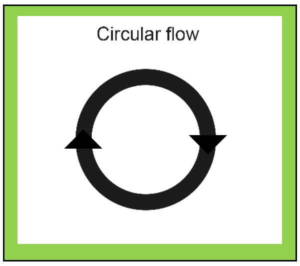

Figure 17: Resource flow categories for the Mirra.

Design approach: Cradle to Cradle

Herman Miller worked closely with McDonough (MBDC) to develop C2C products. To implement this approach, the company dedicated senior staff to act as a core advisory team. This interdisciplinary team represented key sectors of the company: Advance projects, Engineering,

Materials research, Purchasing, Environmental affairs, Finance & Marketing. This team was tasked with analysing and implementing the new measures (McDonough and Braungart 2007). This approach seems to have provided the well-needed support for the Design for Environment team to initiate the changes related to implementing a Cradle to Cradle approach.
For implementing new design measures, a dedicated Design for Environment team (DfE) was formed in addition to the design team, which included a senior engineer, chemical engineer, and purchasing agent. This team developed a "Design for Environment product assessment tool" based on the Cradle to Cradle protocol for material assessment, which evaluates the extent to which the product "is made from 100% biological and/or technical nutrients", taking into account safety, recycled content, recycling potential, and disassembly. According to the product engineer, this dedicated tool was developed to have "an actionable program" with "a good link between the assessment process and an engineer working on a new product design." (McDonough and Braungart 2007). This tool is not used as a generic design tool within Cradle to Cradle Design, but similar assessment criteria are part of the Cradle to Cradle Certification programme (C2C Products Innovation Institute 2012). Apart from this tool, the DfE team could consult experts from MBDC, and they build a material database providing summarised assessment results to the engineers. With the database, designers can also track the content and volume of materials in the product and assess their potential for reuse.

In designing a recyclable chair, the DfE team specifically focussed on material selection and design for disassembly. In material selection at Herman Miller, the use of recycled content and recyclable materials is key, but within Cradle to Cradle also the use of 'healthy' materials is an integral part when closing resource loops. If a material they use contains a chemical that is classified as potentially hazardous, Herman Miller will work with the material's supplier to make changes that eliminate the hazard or to develop or find an alternative material (Herman Miller 2010). The company has described how the C2C protocol has narrowed the designers' freedom in selecting different materials. However, this change is not regarded as problematic, but has resulted in a new focus for the DfE team on how to make the available materials work (Herman Miller 2010). For instance, using this approach the team developed a highly innovative arm rest pad (check term) that no longer employs PVC (Rossi, Charon et al. 2006).
Cradle to Cradle has been criticised for focussing design efforts towards materials, and neglecting energy-related impacts (for instance Bakker et al., 2009). In the case of Herman Miller, energy-related impacts seem well-considered. The embodied energy of materials throughout the lifecycle of a product is analysed and considered in the design phase by setting benchmarks. Furthermore, the company states that it uses 100 percent renewable electrical energy for its worldwide operations (Herman Miller 2010).

Insights from this case

- In view of ResCoM, the design approach used at Herman Miller was Cradle to Cradle, in a design scenario for closing resource flows.
- The adoption of this approach resulted in several distinct design changes related to 'closing the loop' which provided innovative solutions.
- A company specific protocol was developed, with a strong design focus, including methods for assessing progress and a database to manage and transmit data to designers.
- This case offers insights in the organisational structure that can be applied for implementing closed loop design.
- Apart from 'paper-based' methods and tools, the designers were assisted by dedicated experts they could consult.

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4.2.5 Miele & Bundles - Pay per wash

The Miele washing machine “WKG 120 WS” (from the W1 series and from here on called Miele W1) is a top segment laundry machine for the consumer market released in 2014. Its price tag of around € 1200 is three times the price of bottom-end machines and double the price of mid-range machines, but well below top-end laundry machines. The top-end laundry machines for consumers cost around € 3000 and even more expensive machines are available to consumers but these are geared towards professional use. The main benefits that Miele offers as arguments for purchasing the W1-series are a long use life (2 years warranty extendable to 10 years with service certificate), innovative detergent dosage (twinDos and cap dosing) and high energy efficiency (A+++ energy rating) (Miele 2014).

Figure 18: Miele W1 and Bundles Buddy (Credit: wasbundles.nl).

To compare life cycle costs, Table 10 compares the Miele W1 to a bottom-end Indesit and mid-range Zanussi with comparable primary functionality and capacity. Table 10 illustrates that the high purchase price is compensated by the long use life; the calculated price per cycle is about equal. For the Miele machine energy and water costs are 12% below the two alternative machines, but detergent in Miele’s automated dosage system is 14% more expensive. Nevertheless, over-dosage in the conventional system arguably hands the advantage back to Miele in real-life.

In total, the ownership cost of the Miele W1 is comparable to that of a bottom-end or mid-range competitor, and it is probably nicer to have (less noisy, more convenient and only needs replacement after ca. 20 years).

Goal & business case

Albeit that the total costs of ownership of the Miele W1 is comparable to that of competing products in lower segments, the initial purchase price is higher. Since the purchase price influences a consumer decision more than long-term savings, a consumer might choose the less efficient machines that need replacement more often.

Brand	Indesit	Zanussi	Miele
Model name	XWA 71451 WB	ZWN7140AL	WKG 120 WCS
Energy class	A+	A++	A+++
Laundry capacity (kg)	7	8	8
Noise level (dB)	>58	>58	<50
Annual power consumption (kWh)	201	205	176
Annual water consumption (L)	10623	11425	9900
Energy and water costs per cycle* (€)	0.24	0.25	0.22
Detergent unit price (€)	5	5	15
No. of cycles per unit Detergent	14	14	37
Detergent costs per cycle (€)	0.36	0.36	0.40
Approximate sales price (€)	285	550	1200
Use life (cycles)	1200	2200	5000
Machine costs per cycle (€)	0.24	0.25	0.24
Total costs per cycle (€) (energy, water, detergent + machine costs)	0.84	0.86	0.86
Total cost of ownership (€)**	4187	4289	4306
Capacity corrected total cost of ownership (€)***	4785	4289	4306

* using € 0,23 / kWh, € 1,36 / 1000 L and 5000 cycles in 20 years
** for 5000 cycles, assuming that all machines are loaded with the same amount of laundry
*** correction for lower laundry capacity Indesit model (costs per cycle with 8 kg laundry x 5000 cycles)

Table 10: comparison of Miele W1 to bottom-end and mid-range competitors, based on data www.vergelijk.nl (2014); use life (cycles) based on Gemiddeld gezien (2014).

Bundles is a Dutch startup that bridges that gap by offering the use of Miele W1 machines in combination with extended user feedback, detergent, service and lifetime warranty in a package that is paid per bundle of washing cycles. For the average user this service costs € 26/month, with an € 150 deposit as the only initial spend. The total cost of ownership in Table 10 equates to a little over € 15/month, with an initial spend of € 1200, resulting in an overall monthly cost of ownership of about € 16.50 (including interest). The Bundles business case therefore lies in a margin of € 9.50 per month per client that breaks down into wage, costs per instalment, overhead, loans and profit. Choosing a long lasting laundry machine makes much more sense to Bundles than to a consumer, because the lower the cost of service and the lower the risk of financing, the more Bundles profits. Bundles comes with a smart box, the “Bundles’ buddy” on which we elaborate below in the design approach section.

The goal of Marcel Peters, founder of Bundles, is to prevent the sales of cheap washing machines that break and are scrapped within a few years by making a more durable device more accessible. According to Bundles, Miele is enthusiastic about his business idea and the company has attracted 14 pilot customers since March of 2014 using seeding capital. With financial backing the startup plans to scale up to 2400 machines in 2015 (Sprout 2014).

Bundles also plans to span across other product categories with propositions like coffee bundles. The idea is that trough Bundles communities, consumers can influence the design of products, particularly making them long-lasting, upgradable and with less unnecessary features, ultimately reducing their environmental impact (Peters 2014).

Resource flows
Bundles advertises that the Miele W1 is a recyclable machine. Miele does not make explicit mention of this quality. The recyclable claim comes from the notion that most of the machines parts are made from common recyclables like steel and thermoplastics, and that iron is used instead of concrete (ibid). Bundles takes the machine back after use and if possible installs it at another user. Alternatively, the machine is taken back by Miele. No data is available on the further actions taken by Miele (ibid). Arguably they would attempt remanufacture if the core supply is adequate and recycle the machine for its steel content otherwise.
The flow of detergent is linear (not fully biologically degradable). Miele sells cartridges with concentrated detergent and the TwinDos system measures the required dosage to make the detergent use as efficient as possible. The empty cartridge can be refilled with liquid detergent of any brand or it can be put into plastic recycling by the user. Bundles is in conversation with Procter & Gamble to create concentrated detergent refill product of mailbox size, and investigates a process to recycle detergent within the machine with Michael Braungart (ibid).

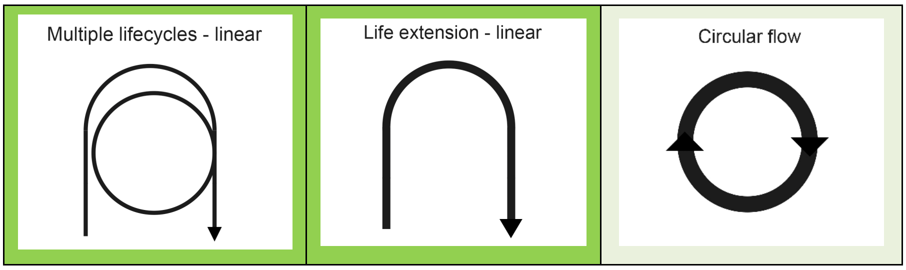

Figure 19: resource flow categories for Miele with Bundles.

Design approach: Design for Life extension
In this section we concentrate on the design of the Bundles system comprising the Buddy product. The Miele W1 is apparently designed for efficiency and longevity but too little data has been published on the design process. The Bundles Buddy is a monitoring system that measures the power consumption of the Miele W1 to count the number of cycles and to deduce the load in the machine. When users only partly fill the drum, the amount of centrifuge cycles decreases but the wear and power consumption are still larger per unit of laundry. An App that comes with the Bundles system alerts users when their behaviour could be improved to extend the product's use life. The Buddy data is also used to monitor malfunctions, predict maintenance and account any refunds if users stay below their bundle. The Buddy and app were developed for Bundles by Shifft, a white label energy monitoring company that mainly works for utility companies like Stedin, Eneco and Evides. The App also allows users to compare their efficiency with other users and with themselves in other periods. In future, Bundles would like Miele to incorporate a monitoring device in the machine with the specific intention to make products last longer by educating users (ibid).

Insights from this case

- The relatively high retail price that comes with long lasting, high-quality products is a barrier for consumers that can be overcome with a pay-per-use proposition.
- Such a pay-per-use proposition is especially attractive when the product is designed with service options in mind, like integrated detergent.
- Monitoring of the Miele W1, which is very efficient by itself, can help users to use the machine even more efficiently through performance comparison and feedback on user behaviour.
- If initiatives like Bundles succeed to create consumer collectives that make more rational and environmentally sound product choices than individual users do, this would create a new business model that manufacturers should take into account.

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4.2.6 Philips - SlimStyle LED lamp

Project goal & business case
A team of designers and engineers at Philips Lighting developed the SlimStyle LED lamp in 2013. At the start of the design process, the team developed a business case for the new-to-be-designed lamp: to develop a low-cost, durable, high-quality LED lamp that can compete with other low-cost LED lamps in the market. This was the starting point for the design. In the subsequent phase of the design process, the concept for the lamp was created. Cost reduction was achieved by elimination of the heat sink. Durability was ensured through a rigid design, using polycarbonate for the bulb, which also led to the characteristic shape (the 'slim style'). After the business case for the lamp was validated, a detailed design was developed, followed by a number of working prototypes and small series. In the final design stages the lamp was released for production.

Resource flows
In terms of resource conservation, the SlimStyle LED lamp slows the flow of resources through lifetime extension: the lamp has been rated for a life of 25,000 hours (15 - 20 years). This is roughly 30 times longer than incandescent bulbs and 5 times longer than compact fluorescents. A long life is not extraordinary for LED lamps, but not all LED manufacturers use high-quality LEDS and electronics. Degradation of the driver electronics, for instance, can cause early failure in LED lamps.
In principle, this design could also close resource flows ("primary recycling"), as the design enables recycling of part of the resources used. Philips has however no control or influence over the recycling infrastructure, and in practice secondary recycling is a more likely option. Nevertheless, this case was specifically selected also for addressing the closing of resource flows, as it offers a best practice for the way companies handle the recycling of products with electronic components. This type of products, which is relevant to several of the industry partners, require a different approach to recycling than the other best practices in closing resource flows (Full Circle Design and Herman Miller).

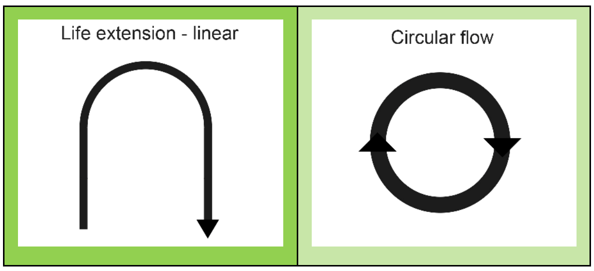

Figure 20: Resource flow categories for the SlimStyle.

Design approach: recycling & product life extension
The Philips lighting designers and engineers are supported in the early stages of their development process through quick and easy methods, such as lookup tables, reference books with inspirational examples, and guidelines. For selecting materials, they use internal databases with restricted substances and preferred materials. Simplified LCA tools are available to indicate hotspot environmental impacts, based on the BoM (bill of materials).
Based on common sense, design for recycling was selected as the most viable end-of-life option, as widely dispersed, long life and low-cost electronic products don't make a very good remanufacturing case (costs and impacts needed for transport compare unfavourably against the low value of the product).

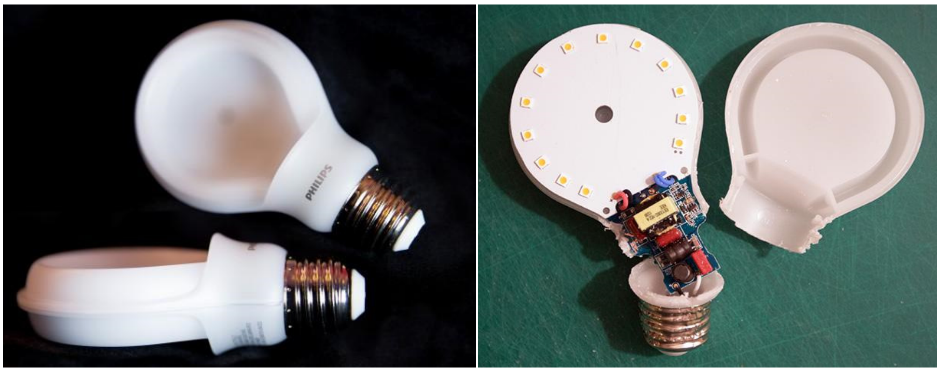

Figure 21: SlimStyle lamp (left) and disassembled lamp (right) (Credit: Philips).

Report D2.2 has presented the Design for Recycling guidelines that Philips developed for the design of this lamp, based on shredder tests. This approach illuminates the need at Philips to develop context-specific guidelines for the design team that are tuned both to the product type (LED lighting) and the specific recycling processes. Following the guidelines, the team addressed material selection (choice of recyclable and compatible materials, using look-up tables) and connections (choice of connections that separate easily in the recycling process, again using look-up tables). The overall aim was to strive for the cleanest possible fractions after shredding and sorting, with a special emphasis on the liberation of those parts with the highest residual value (i.e. Copper, PCB assembly).

The polycarbonate parts of the bulb are connected through ultrasonic welding such that the connection is strong enough in normal use, but breaks apart in recycling. This was tested during the prototype stage by simple improvised tests, such as the “bench vice” test to simulate shredding. During the EU GreenElec project, a number of SlimStyle lamps were shredded at a recycling plant, which provided real-life validation for the recyclability of the lamp.

Insights from this case

- Philips uses a typical stage-gate process for product development.
- In view of ResCoM, the design approaches used were design for recycling and product life extension.
- The Philips Lighting designers and engineers are offered a range of tools, most of these specifically developed for the design of LED lamps and luminaires, and containing confidential company data (for instance economic data).
- Philips is currently adding specific design for recycling tools. For Philips, being clear on priorities is very important: where should the designer/engineer look first? What should be the first decision/step taken? In the case of design for recycling, the first step is to determine the parts/materials with the highest residual value, and ensure that these will come out as “clean” as possible in the recycling process.
- Despite their efforts to embed recycling considerations in the design process, it is our impression that Philips designers are struggling to take these extra criteria on board, as the business case for ‘design for recycling’ is feeble (at best). However, in the case of the SlimStyle, the measures could be integrated without adding cost, while improved recyclability contributes to the Philips ‘EcoVision’ on sustainability.

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4.2.7 Roetz-bikes – 'Public-transport' bicycle

Project goal & business case

Roetz-bikes is a company that produces bicycles made from discarded bicycles. In 2014, the company started a pilot-project for NS (Dutch railways) to remanufacture the 'OV-fiets' (translated: public-transport bicycle). The OV-fiets is a bicycle that commuters can rent at railway-stations for follow-up transport. In the same year, NS had a total volume of 3000 rental bicycles across the Netherlands that were rented out 1.5 million times (that year), with 180,000 users (NS 2014, Trouw 2014). The bicycle has been specifically designed for NS. The bicycles are rented out for four years after which they are taken out of service. Goal of the remanufacturing project is to supply NS with remanufactured public-transport bicycles at a price that is similar to that of the new product. In addition, Roetz aims to achieve less malfunctions with the remanufactured design (OV-magazine, 2014). For NS, this project contributes to their aim of sustainable business operations (Trouw, 2014).

The company succeeds in producing the bicycles at a similar price as new bicycles (about Eur. 250) due to the reduced part costs (NS provides the depreciated bicycle at no cost). The company is a so-called Social Enterprise, and the bicycles are remanufactured locally (in the Netherlands) by people with a distance to the labour market. According to Roetz, this practice is not initiated to reduce labour costs. These are similar, because the lower wages are compensated by the additional time needed for training. Instead, the company has this model to contribute to social sustainability (Trouw, 2014, OneWorld, 2015). After a successful pilot of 100 bicycles, the company will start to remanufacture approximately 1000 bicycles per year for the next three years, which will save 14.5 ton bicycle parts per year (Nederland circulair, 2015). Due to expansion of the public bicycle rental business, NS will additionally purchase at least 3000 new bicycles in the coming 3 years (OV-magazine, 2015).

Resource flows

Roetz receives bicycles from NS and these are inspected, disassembled, cleaned, processed, and assembled (Roetz-bikes, 2016b). During this remanufacturing process, the bicycles are genuinely returned to as-new condition, and are delivered to serve another full service life of 4 to 5 years. Almost 70% of the bicycle (weight) can be remanufactured, especially the locks, frames, front fork, luggage carriers and wheels (see figure 23, Roetz-bikes 2016a). Moving parts, such as bearings, grips and gear case are generally replaced due to wear (OV-magazine, 2014).

As the considered products are almost entirely metal and thus recast, this information leads us to believe that this is an example of circular multiple lifecycle resource flows. Furthermore, the bicycles have been specifically designed for NS by another company, Bikes2Go, to withstand intensive use, so the bicycle can also be considered a best practice of design for extended product life, based on a linear system (figure 22).

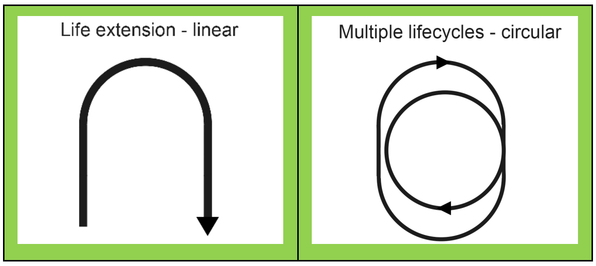

Figure 22: resource flows for the OV-fiets.

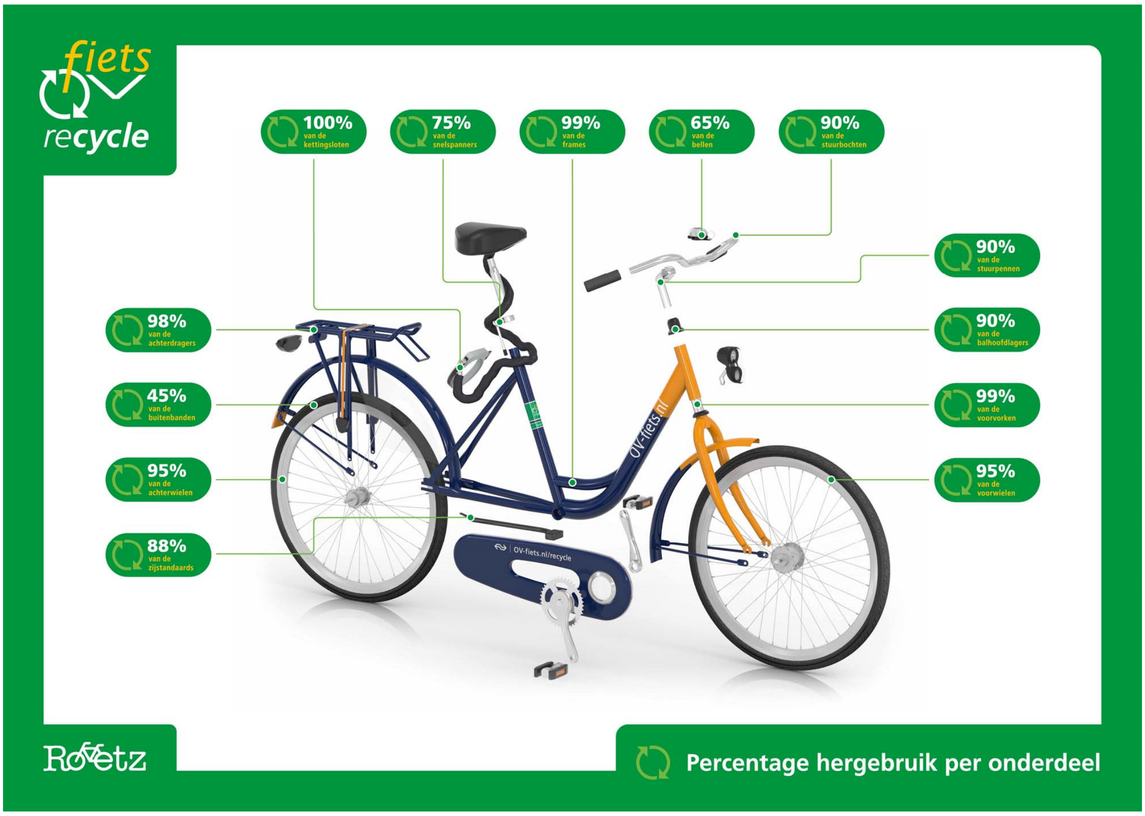

Figure 23: reuse percentages per part (Credit: Roetz-bikes).

Design approach: remanufacturing & product life extension
The bicycle has been designed specifically for NS (by Bikes2Go) to meet the requirements of the customers (comfort, aesthetics) and of NS (durability, cost of maintenance). Its features include broad tires, robust frame, luggage carrier, sturdy coat protectors, and a unique design, to prevent theft (www.treinreiziger.nl 2009). In 2016, a new design will be introduced with integrated headlight and larger luggage carrier (OV-magazine 2015).
Also during remanufacturing, design improvements are implemented. For instance, the position of the lock was slightly altered to improve ergonomics, a saddle-lock (to prevent theft of the saddles) was added, as well as improved lighting without batteries (Trouw 2014). The selection of improvements is pragmatic, based on a list of 'user frustrations' (Roetz-bikes, 2016). In the other bicycles that Roetz produces from discarded bicycles, they design the bicycles in a way that facilitates future reuse of parts, to which they specifically refer as an approach of design for remanufacturing (Nederland circulair, 2015).

Insights from this case

- In view of ResCoM, the design approaches used were design for remanufacturing and product life extension.
- In this case, Roetz-bikes succeeds in offering as new quality for the same purpose.
- Due to the relatively large fleet of products, a high remanufacturing percentage is achieved, which is measured based on kilograms reused parts.
- The product is offered by their client to consumers via an innovative, "pay-per-use" rental model.

- The original manufacturing and the remanufacturing are provided by different companies, and the new products have not been optimised for remanufacturing.
- The business case for remanufacturing is built on the cooperation of Roetz-bikes with their client NS, who supplies the depreciated bicycles to Roetz.
- The client, NS, formulates the product design specifications.

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4.2.8 Scania - Trucks

Scania AB is a major Swedish automotive industry manufacturer of commercial vehicles - specifically heavy trucks and buses. It also manufactures diesel engines for motive power of heavy vehicles, marine, and general industrial applications.

Resource flows
With respect to resource conservation, the Scania design approach is not directly aimed at closing resource loops, but this approach was identified as facilitating the reuse of parts over multiple lifecycles with high economic potential with regard to the successful implementation of closed loop product systems (Figure 24). Scania currently practices component reuse/ remanufacturing primarily for its after sales support programme. In this programme, called Scania Service Exchange, the company is remanufacturing large number of truck components including, among several others, alternators, crank shafts, steering gears, gear boxes and engines. An important feature of this programme is that the company encourages replacement of modules over repair of the components; the company-remanufactured modules are sold at a lower price as compared to new components but with similar warranties (Scania 2013).
As far the design process is concerned, the designers in Scania actively evaluate their designs in the disassembly process. The ease in product disassembly and assembly due to company's modular design and management approach has made the product remanufacturing easier. Nevertheless, the company doesn't remanufacture the entire product i.e. the truck, since Scania doesn't want the remanufactured trucks competing with its new trucks in the same market (Sundin 2006).
In order to ensure a reliable supply of the used components (cores) the company has a facility that buys trucks that are in some way damaged, and cannibalise them for valuable components for reuse and remanufacturing. The main source of trucks in this case is those that have been damaged and are supplied by insurance companies (Östlin 2008).

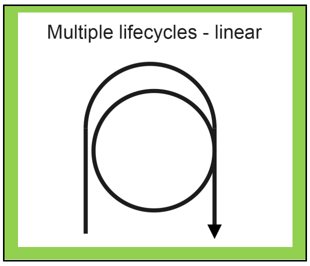

Figure 24: Resource flow category for Scania Trucks.

Design approach: Modular design
As pioneer of developing trucks based upon a modular philosophy, Scania sought competitive advantage in responding to different market demands for tailored solution while satisfying demands for more economical production. One example of the benefits achieved can be seen in the Key Performance Indicators for the Cab as shown in Figure 25. Successful implementations of modularized products can be found throughout automotive industry (Johnson 2013), but has as well reached other industries as, for instance, home appliances like microwave ovens from Whirlpool (Modular Management 2013).

Scania Cab: Commonality from Modularity			
Category	**Before**	**After**	**Reduction**
Sheet metal parts	1400	380	72%
Interior fittings	1800	600	67%
Parts in cab roof	7	3	57%
Parts in front	8	3	62%
Parts in doors	12	8	33%
Wind shields	3	1	67%
Sheet metal tools	1600	380	83%

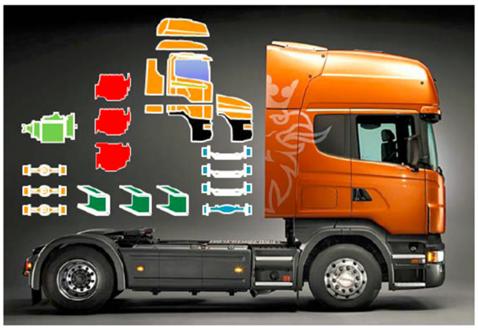

Figure 25: Effect of modularization on number of parts for a Scania truck cab [4] (Credit: Scania).

The competitive advantages of applying modular design and management principles in the linear manufacturing systems as summarised in case of the Scania example are:

- Gives customers an exceptionally wide choice that enables vehicles to be tailored to any type of transport
- Increases access to parts on a global basis
- Simplifies repairs and servicing
- Shortens downtime
- Ensures a high, uniform quality level at workshops
- Product similarity secures high competence in the service network.

This list of advantages indicates that the platform approach and modular design of components contains potential when it comes to facilitating the realization of closed loop product systems in the ResCoM perspective. For example, implementation of service-based business models - where the manufacturing companies retain the ownership of their products - can be facilitated through a modular management approach From a design and business perspective major challenges are anticipated in the standardization of interfaces, coordination of components, modules and products in an integrated supply chain, as already indicated in deliverable D2.2 (chapter 4.2). High potentials and benefits are anticipated with regard to service, maintenance and product upgradeability in a closed loop with multiple lifecycle product lifecycles. Hence, modular design approaches need to be considered for the ResCoM design methodology in line with appropriate product life cycle and value management strategies.

Insights from this case

- In view of ResCoM, the design approach used is modular design standardization of components, modules and interfaces. This approach offers advantages such as easy assembly and disassembly, minimizing product complexity and flexibility in product customization.
- This modular approach facilitates the replacement, reuse and remanufacturing of components or modules, providing the company a competitive edge from a technical and business perspective.
- The modular design that facilitates the remanufacturing enables the company to realise a unique business offering in after sales service where the company provides spare components / modules which are cheaper than new ones but still have the same quality and warranties.

References

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4.2.9 Xerox - Printers

Xerox is an American company that designs and manufactures printers, copiers and digital presses for offices. These are offered as stand-alone devices with optional extended warranty and exchange service, but Xerox's core business is to offer their products in product service systems, combining the use of their products with maintenance, exchange and pick-up service and document management through lease contracts.
Remanufacturing at Xerox began in the 1990's and it is one of the well-known examples of a company where remanufacture, service and upgradability are truly embedded in the product development process. Remanufactured output now accounts for 25% of Xerox's total output. Xerox is leading in remanufacture and since 1991 they recovered over 2.8 million devices (Gray and Charter 2007, Hegland 2010).

Project goal & business case
Remanufacture is integral to Xerox' zero waste and environmental impact reduction commitment. Ambitious targets are set for greenhouse gas emissions, energy use, hazardous compounds and solid waste, which are being met with strategies for production efficiency, product reliability and remanufacture (Xerox 2012). The Xerox business case is compelling; in 1991 alone a saving of $200 million was reported by remanufacturing copiers after their lease had ended (Ferguson and Souza 2010).

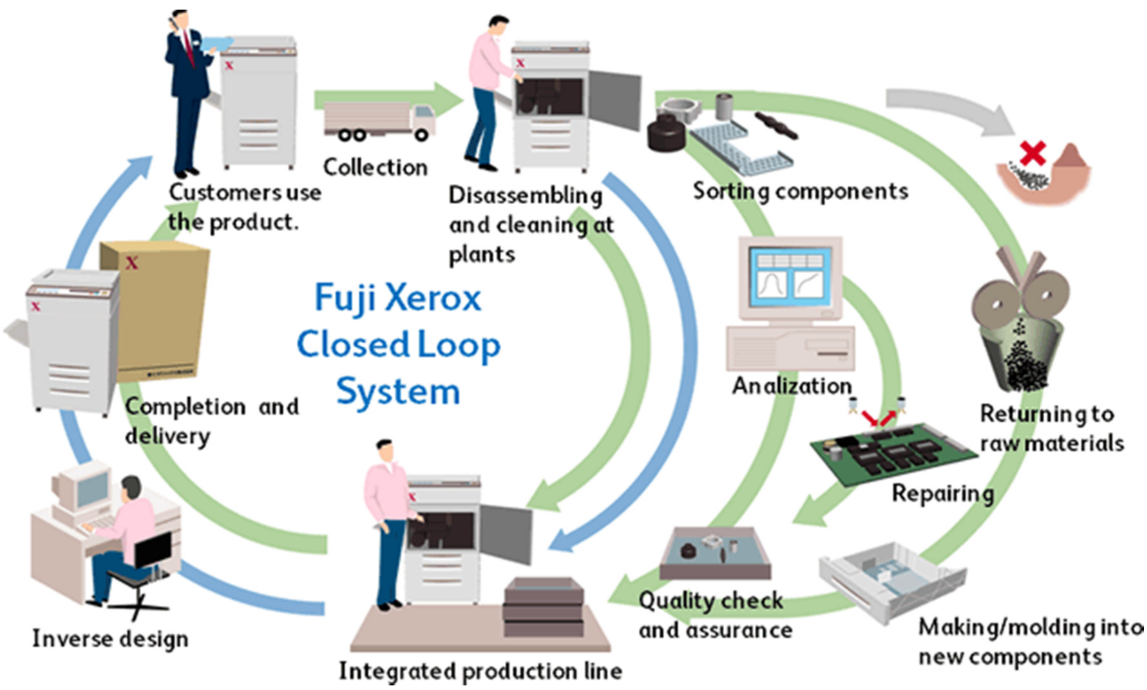

Figure 26: Fuji Xerox Closed Loop System [6].

Resource flows
The lease programme ensures a high rate of returns as Xerox remains owner of the products. The products are remanufactured and can have up to 7 lives (Gray and Charter 2007), and thereafter the recycle rate for predominant platforms is 96% (Hegland 2010). Consequently, this case has been categorised as a circular multiple lifecycle flow (Figure 27).

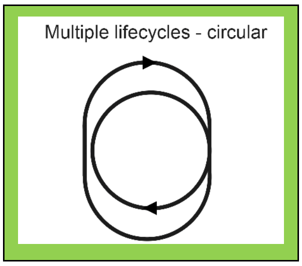

Figure 27: Resource flow category for Xerox Printers.

Design approach: Design for Remanufacture and Upgradability
In their design for new products, Xerox spends considerable attention to make them future proof. Looking five years ahead, Xerox plots out upgrade plans and determines which components should be designed for replacement and which should be designed for reuse (Gutowski et al. 2001). Furthermore a platform-based modular product architecture allows the fast-changing and long-lasting components to fulfil their respective lifetimes.

According to Jack Azar, Xerox VP for Environment, Health & Safety: “Xerox products are designed to reduce environmental impacts in all phases of the life cycle. We design our products for remanufacturing and design imaging supply items for return, reuse and recycling. These early decisions mean that once the product's supply item or the product itself has reached its end-of-life, we maximize the assets and minimize the waste.” (in Gray and Charter 2007, p.40)

The publication by Gray and Charter (ibid) takes learning from practices and case studies mainly at Xerox and also at Perking Engines (today CAT REMAN), Milikin carpets and InfoTeam. The authors created the insightful Table 11 that matches the needs of the remanufacturing process with design strategies that help to meet them. At Xerox specifically the products are designed with the entire life cycle known, designed for disassembly and designed for part durability. Disassembly especially influences the cost efficiency of the remanufacture process as it determines the time spent on various sub-tasks like inspection, cleaning and reassembly.

Insights from this case

- A leasing contract where the manufacturer retains product ownership is a way to ensure sufficiency of cores
- A multi-year plan for upgrades allows distinction between long-lasting platform components and fast-changing modules
- Design for disassembly is vital to the profitability of remanufacturing.

DESIGN STRATEGY	REMANUFACTURING PROCESS						
	Core Collection	Inspection	Disassembly	Cleaning & storage	Remediation	Reassembly	Testing
Design for Core Collection	√	√					
Eco-Design		√	√	√		√	
Design for Disassembly		√	√	√	√	√	
Design for Multiple Lifecycles				√	√		
Design for Upgrade					√		
Design for Evaluation		√					√

Table 11: Design strategies that aid the remanufacture process (Gray and Charter 2007).

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4.3 Conclusions from the best design practices

RQ4: What design methodology is applied in these best practices that can contribute to the ResCoM methodology (such as design strategies, methods, and tools)?

RA4.1: In the best practices we have found several design approaches that have been applied for the different design scenarios and resource flows, summarised in Table 12. Furthermore, a limited number of methods and tools has been found useful in the design process. However, not one approach, method and tool seems generally applicable for a ResCoM design methodology due to differences in specifications and design processes. In multiple best practices, the approaches, methods and tools were specifically tuned to the company and product-system.

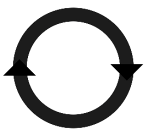
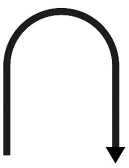
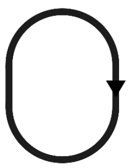
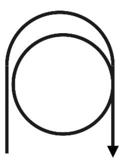
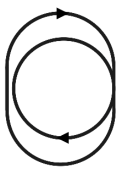
Resource flows:	Design approaches in best practices (case numbers)
Circular flow 	• Cradle to Cradle - closed loop (BP 3 & 4) • Design for Recycling - open loop (BP 6)
Life extension - linear  Life extension - circular 	• System engineering (BP 1) • Generic design approach (BP 3, 5)
Multiple lifecycles - linear  Multiple lifecycles - circular 	• Design for Remanufacturing (BP 2, 7, 9) • Modular design (BP 8) • Generic design approach (BP 3).

Table 12: Summary of design approaches used for different resource flows.

RA4.2: From the literature study we additionally identified the following specific design-related activities (DA) as complementing the generic design approach:

DA 1. Consider the different End-of-life scenarios of repair/upgrade, remanufacture and recycling by trying them out on existing products at the start of the design process.

DA 2. Develop bespoke tools for the company to support designers and engineers in their information and evaluation needs.

DA 3. Define principles (not only requirements) to guide the design process and induce innovations.

DA 4. Design the product, material loops and service system in parallel.

DA 5. Use system engineering for platform based design.

DA 6. Adopt a PLM system to manage the flow of new, used and updated modules.

DA 7. When designing a reverse supply chain, consider using dealerships as the start of the chain (for gathering and returning products to the manufacturer).

DA 8. Consider a deposit system to incentivize product returns.

5. Conclusions

By combining the findings from the current design practices at the OEMs involved in ResCoM with best practices in industry on specific closed-loop design scenarios, methodological gaps for the ResCoM design method are identified, as well as critical success factors for its implementation.

5.1 Methodological coverage & gaps

RQ5: What key methodological gaps need to be closed to go from current design practices to ideal ResCoM cases?

The ResCoM design method needs to be integrated in the existing product development process. The analysis of current design practices showed where in the design process additional or altered methods and tools are needed. The study of best practices showed how existing approaches, methods and tools are used in external cases to develop closed-loop designs. The findings are summarized in Table 13.

Gaps identified from current practices	Gaps addressed by best practices
- Focus on first design phases	DA 1, 2 and 3 specifically address phase zero DA 4 and 5 address stage 1
- Intervene in the selection of alternatives	DA 2 creates company specific assessment tools for selecting between alternatives > General guidelines or a general approach could aid this process in early stages
- Intervene in the evaluation of the prototype	Matches DA 1; show how company (and ResCoM scenario) specific validation methods were developed for assessing prototypes
- Support throughout different stages	> No detailed approach was found that addressed the different stages
- Offer solution-finding tools	> DA 1 and 3 offer inspiration, but a creative tool applicable to ResCoM is called for.
- Be company specific	Matches findings from best practices
- Primarily support redesign/incremental innovation	DA 1 and 5 target this kind of innovation > Best practices indicate that to close loops, more than incremental innovation is required at the component level
- Neutral to specific software	> Best practices 1, 2, 4, and 5 indicate that company specific approaches are used instead.

Table 13: Methodological coverage and gaps for a ResCoM design approach. 'DA numbers' refer to specific Design Activities, mentioned in section 4.3; ">" refers to remaining gaps)

The specific approaches identified in Chapter 4 (summarised in Table 12) will be used for the development of a ResCoM design methodology. However, the findings from both the internal and external best practices highlight the importance of developing context-specific methods and tools (specific in terms of the company and product-system). In fact, it is becoming clear that a useful method would not be generally applicable since the information needs, interesting design approaches, and applicable end-of-life scenarios are quite different for each type of product-system. In the best practices that were reviewed in this report, the companies have taken initiative to create a method that worked for them and specifically for one product (family). And that, discovering what is needed to implement ResCoM in a given case, in itself could be made into a general method that creates context-specific methods.

5.2 Critical success factors

RQ6: Which critical success factors can be identified from the current and best practices for the development of the ResCoM methodology?

Both from the current design practices and best practices, critical success factors were identified. The link to a sound business case was illustrated in several best practices, and identified as critical by the OEMs. In the best practices, examples have been provided of how (part of) a ResCoM approach can build or support a solid business case, but as only successful cases were included in the analysis, no further details are described as to how to establish such a business case. This topic is addressed in WP4.

With respect to the design approach, method and tools, the critical success factors are related to fitting the particular needs and requirements of designers and engineers. These success factors, summarised in Table 14, will be taken into account as requirements for the development of the ResCoM design methodology in D3.3.

In addition, the best practices illuminated that the designers and engineers had, or were granted the design freedom to implement drastic design solutions for meeting ResCoM-related requirements. Consequently, the designers often worked closely with other disciplines within or outside the company. The organisational impacts of this process should be well-addressed within the follow-up project activities, to ensure a successful implementation of ResCoM.

Critical success factors	Addressed by OEMs	Addressed by Best Practices
What should methods/tools offer:		
• provide insights / educate: what are options, and “what happens if…”	v	
• compare/assess design alternatives	v	v
• provide/exchange information such as company disciplines; material data	v	v
How should they offer content:		
• easy to learn, provide ‘fast’ results	v	v
• provide clear options, but: insightful	v	v
• tuned to different phases, i.e. intuitive in phases 0 and 1; more detailed and quantitative in later phases	v	
• provide visual results: for designers and management	v	
• fit into existing workflow, specifically the use of requirements, CAD, and prototypes	v	v

Table 14: Critical success factors for the application of ResCoM methods and tools.