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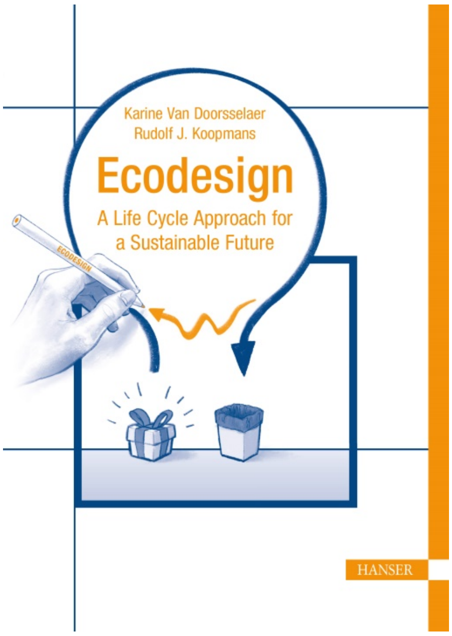

Sample Pages

Ecodesign

Karine Van Doorsselaer and Rudolf J. Koopmans

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Acknowledgments

In 1995, I taught the course “Ecodesign” for the first time. In those days, among consumers, “ecodesign” was perceived to relate to products made out of biomaterials or to making art out of discarded products. For companies, implementing ecodesign in the design process was considered a time- and money-consuming effort, bringing benefits for other stakeholders in the value chain. For example, the “design for recycling” guidelines favor the recycling companies, but do not provide any benefit to the company producing a product.

Now, 25 years later, ecodesign is considered as a key to success for the transition to a circular economy model in which the development of new business models and close value chain stakeholder collaboration is the challenge. The notion that the environmental impact and circularity of products are particularly determined during the design phase, the phase in which numerous choices are made, has pervaded.

The hope is that in the next 25 years we can look back on a successful transition period to a sustainable, livable society with respect for fauna, flora, and all the natural resources.

The reset of the economy worldwide after the Corona pandemic, now in 2020, is the perfect opportunity to invest in industries and business models based on the principles of sustainability and circularity. Governmental actions already have been taken by the EU, with, for example, the “European Green Deal”. Growing environmental concerns of consumers support the economic and industrial shift towards a sustainable world.

Special thanks to the co-author of this book, Prof. Dr. Rudolf Koopmans. He proposed to translate and rework the Dutch-language book *Ecodesign*. He broadened the scope of the book by inserting extra interesting information. He also took care of the enormous editorial work, so I could concentrate on the content of the book. We have learned from each other. The intense collaboration was my invitation to describe and articulate the ecodesign theory very carefully, so that no misunderstandings may arise.

Furthermore, I would like to thank my colleagues from the Department Product Development of the University Antwerp, Belgium. Many thanks to Mr. Wim Maes for making the nice figures according to the house style of the book; Prof. Dr. Alexis Jacoby, for his contribution on the state-of-the-art information concerning the design methodology; and Prof. Dr. Ingrid Moons, for the explanation of some economic themes.

Many thanks go to Simon De Meulenaer, the cartoonist of the book. His beautiful cartoons give an extra look to the book.

I also would like to thank the graduates of the Department Product Development of the University Antwerp in Belgium for their presentation of their master's theses: Frederik Carette, Laure Herweyers, Thomas Roscam, Nicholas Van Beylen, and Robrecht Vandekerkhove.

And finally, I would like to thank those responsible at the publishing house Carl Hanser Verlag for giving us the opportunity to spread our knowledge about ecodesign.

Karine Van Doorsselaer – Antwerp, Belgium – October 2020

The future is unpredictable as unplanned events can change the course of history. In 2017, having been invited by the European Commission to participate in a team of experts for writing up what the R & I (research and innovation) state of play of plastics was (A Circular Economy for Plastics – 2019), I first met Prof. Dr. Karine van Doorsselaer. Her interest in and passion for sustainability was so stimulating that I invited her to give a talk on the topic at our PICC – Plastics Update Conference in November 2019 in Fribourg, Switzerland. During our joint dinner, the same evening she mentioned having written a book, *Ecodesign*, in Dutch and promised to send me a copy. She did and I read the book in a few days. The book was so inspirational that I asked her about an English version to reach a larger audience. When I said I would do the translation and spend the time needed, Karine agreed to go for the English version as suggested. So I set off on a challenging journey that quickly became more than "just me translating" and resulted in conceiving together a new book. On March 15, 2020, the Corona pandemic forced us to stay home, which actually enabled me to finish the job. In the endeavor I also got some help from my native-speaking English/American friends, who were kind enough to read the first version and provide some insightful suggestions as well as some spelling improvements. Thank you, Malcolm, thank you, Bob!

Overall for me, it was a rewarding experience in which I learned a lot. The available information (and some disinformation) on the topic of sustainability and associated themes is so overwhelming, it becomes difficult to see the forest for the trees. And I think I can speak for Karine and me: this book is a good starting point to see the forest and find a path through the trees. Enjoy!

Rudy Koopmans – Halle, Germany – October 2020

About the Authors

Prof. Dr. **Karine Van Doorsselaer** (born in Belgium in 1965) graduated in 1986 from the University of Ghent, Belgium, as industrial engineer in chemistry with specialization in plastics. In 1990 she finalized the program "Human Ecology" at the University of Brussels, where in 1999 she obtained her PhD in human ecology.

Between 1986 and 1990, Karine worked in the technical laboratory "Polymers" of Exxon Chemical. In April 1990 she switched to the academic world and started as assistant in the polymer laboratory at the department Product Development of the University of Antwerp, Belgium, later being promoted to lecturer (in 1995) and senior lecturer (in 2016). Since 1995 she teaches the course "Materials Science, Selection of Materials and Production Techniques". In that same year, she set up the course "Ecodesign". For a quarter of a century, Karine has been guiding future designers into the world of materials and on how they can design products that fit in a sustainable and circular economy. She is often invited to various educational institutions and companies to provide knowledge and advice on ecodesign, and has worked on numerous government projects to integrate ecodesign into policies.

Prof. Dr. **Rudolf (Rudy) J. Koopmans** fosters creative thinking that stimulates innovative science and technology, and advances application development that contributes to a sustainable society. Presently, he is Director of the Plastics Innovation Competence Center (PICC – www.picc.center), Director of the Institute of Applied Plastics Research, and Professor at the University of Applied Sciences and Arts of Western Switzerland (HES-SO–HEIA-FR) in Fribourg (FR). As owner of Koopmans Consulting GmbH, located in Zürich, Switzerland, he provides industry consultancy on innovation and sustainability challenges. As a former R&D Fellow at The Dow Chemical Company, he brings more than 35 years of experience in the plastics industry. As a PhD graduate in physical and macromolecular chemistry (University of Antwerp – Belgium) and Master in Business Administration (KU Leuven – Belgium / INSEAD – France), he combines deep technical knowledge with business metrics to advance evolutionary and disruptive innovation.

At ETH Zürich (Switzerland), he lectures at the Department of Materials Sciences, where he also received the Staudinger-Dürer Medal for excellence in Materials Science. He is member of the Wetenschappelijke Advies Raad of Catalisti for advising on R&D projects for the Region of Flanders (Belgium). In addition, he is board member of the Swiss Plastics Cluster, Kunststoff Ausbildungs und Technologie Zentrum (KATZ) (Switzerland), expert evaluator for the EU Research and Innovation Framework Programmes, and assembly member of the Horizon Europe Mission Healthy Oceans, Seas, Coastal, and Inland Waters.

He has published more than 70 papers in international journals, contributed several book chapters, wrote or co-wrote four books, presented multiple keynotes at international conferences, and is holder of 22 patents.

The cartoons at the beginning of each chapter and on the cover of this book are the work of **Simon De Meulenaer**. Simon graduated in 2015 with a Master in Product Development from the University of Antwerp, Belgium.

Contents

- ✓ The concept suggests that an unlimited economic and population growth is feasible if done in the right way. The Earth, however, has sustainability limits.
- ✓ The consequences of C2C systems for transport (disassembly and reuse of products induces more traffic) and energy consumption (recycling costs energy) are not sufficiently thought through.
- ✓ Upcycling is a term much used in the book. It means that the recycled materials have a higher quality then the prime materials. For most materials this is an illusion. The state-of-the-art recycling technologies have a hard time avoiding impurities or degrading the materials, with exceptions for glass and some metals. Garden benches made of recycled plastics are considered as downcycling. Turning PET bottles into fleece fibers is also considered as downcycling. Does a bottle have more value than a fleece pullover? Upcycling is also used for after-use products that are repurposed into new products of higher value with a different function. An example is flexible PU mattresses that are turned into aqua gardens in refugee camps [16]. For most products upcycling is a challenging task and difficult to scale at an industry level where it becomes a debatable practice.
- ✓ Certification is an expensive process and the Cradle to Cradle Products Innovation Institute has a monopoly position.

Introducing novel insight and business models is always likely to generate criticism. The more disruptive the proposed change, the more distrust and resistance is created. Change puts into question long accepted practices which for some are a real threat to their existence.

Nevertheless, the cradle to cradle concept has introduced some new thinking and has paved a path towards the circular economy model. In the 1990s, the early days of ecodesign, the focus was mainly on integrated chain management, which became *de facto* cradle to grave. Since 2010, more environmental awareness has resulted in the cradle to cradle concept being referenced in governmental texts but without pointing at the C2C private certification initiative. This inclusion would raise issues of conflict of interest.

As a consequence, the cradle to cradle concept has a double meaning of referring to the private C2C certification and as an ecodesign approach in which the designer aims at a product development across the entire life cycle, which is a closed loop and aligns with the circular economy model [17].

3.4 The Circular Economy Model

In Chapter 2 the take-make-waste practice captured in a so-called linear economy model is highlighted [18]. In 2020, this model is still an everyday practice, even though many have argued for change. The idea of circular materials streams had been already presented in 1966 by Kenneth E. Boulding in his paper “The Economics of the Coming Spaceship Earth” [19]. More than 50 years later, the Ellen MacArthur Foundation made the message stick. Financial institutions, companies, non-profit organizations, NGO's, and governments have jumped onto the bandwagon to implement a circular economy model.

Certainly, the European Commission is driving the circular economy model, realizing that the continent has little raw materials, which makes Europe financially very dependent on other continents, and that is a very uncomfortable situation [20, 21]. Keeping (local) natural resources and materials in a closed loop and exploiting possible regional strengths not only makes environmental sense but it also addresses economic and political desires. As a result, in 2019, the European Commission launched a policy for implementing a circular economy model: "The European Green Deal". This new strategy aims to transform the EU into a fair and prosperous society with a modern, resource-efficient, and competitive economy that will be carbon-neutral in 2050 and where economic growth is decoupled from resource use [22].

3.4.1 The Principles of a Circular Economy Model

The circular economy model is visually represented as originally shown by the Ellen MacArthur Foundation, with a so-called butterfly graphic reminiscent of the two cradle to cradle cycles. The circular economy model implies, however, much more than closing the loops for the materials (Chapter 5) as it encompasses a system approach that includes the circularity of a product (Figure 3.7).

The "wings of the butterfly" represent the bio-sphere and the techno-sphere. Materials can be extracted from biomass or from ores and minerals. The "body of the butterfly" embodies the steps in the life cycle of the product, from the raw materials through the use stage. After the use of products, incineration or landfill are not an option. The products, the parts, and the materials are kept in closed circles. The products and parts need to be repairable, upgradeable, easy to maintain, and capable of being refurbished, while the materials should fit into the recycling/composting processes. Materials need to be as clean as possible to be recycled or transformed into feedstock or building blocks. It means that any added substances, e. g., additives in plastics, inks, glues, should be used sparingly or avoided, unless they are harmless or easily removable during the recycling process. This puts additional constraints on the design of the products, as the materials should be recyclable many times without the accumulation of contaminants or hazardous or toxic substances.

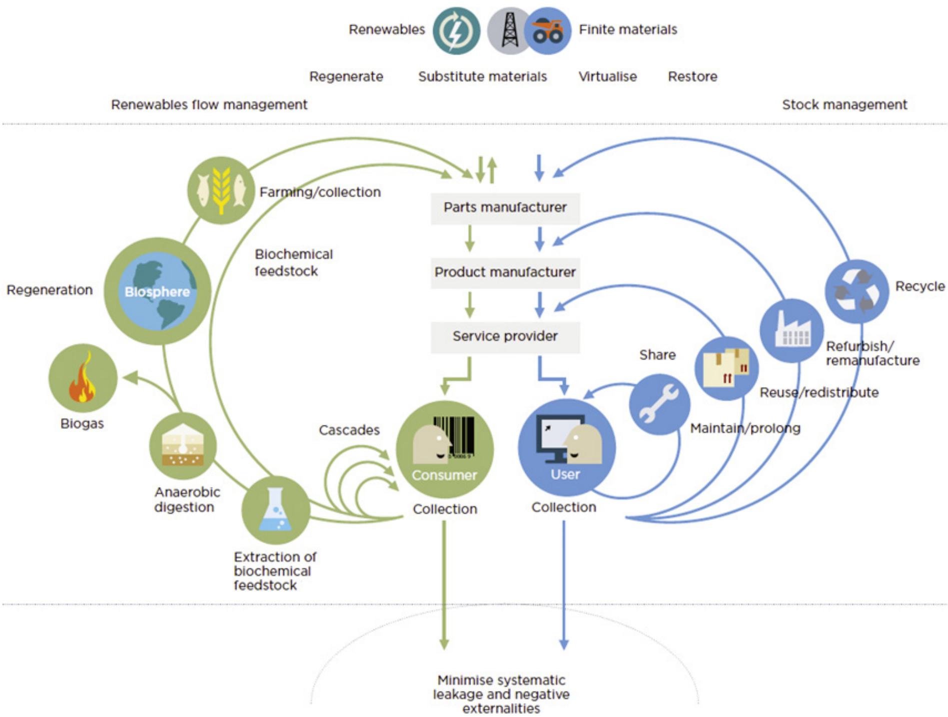

Figure 3.7 Visual representation of the circular economy model [18]
Reproduced with permission from The Ellen MacArthur Foundation. Source: Ellen MacArthur Foundation, SUN, and McKinsey Center for Business and Environment, drawing from Braungart & McDonough from Cradle to Cradle (C2C)

The basic principles of the circular economy model are:

- ✓ Value preservation is maximized by first considering product reuse, then part reuse, and finally materials reuse (recycling).
- ✓ Products are designed and produced such that after use they can be easily disassembled, enabling easy separation of different materials.
- ✓ During production, use, and after-use processing of the product no harmful substances should be emitted.
- ✓ Parts and materials of durable products (e. g., smartphones) should be reused without quality loss.
- ✓ Parts and materials of consumer products (e. g., toothpaste) should be biodegradable and after removal of valuable materials be given back to nature.
- ✓ Offer services instead of products. Producers remain owner of the consumer products and customers pay per use, not for ownership. Another possibility is the repurchase by the producer at the end of the product's life span. Delivering the right quality becomes very important for the producer because the product performance defines the value. High-quality products tend to have longer life spans.

- ✓ Value chain collaboration is necessary in a circular economy. The designer is the conductor of the behaviors of all the stakeholders in the value chain.

The key thoughts of a circular economy model are:

- ✓ No waste
- ✓ All has value
- ✓ Renewable energy
- ✓ Pricing reflecting true cost
- ✓ Agility for diversity

Ecodesign is the guiding principle during the product development process in order to make products and services that fit in a circular economy model.

3.4.2 Value Preservation in the Circular Economy Model

The transition to the circular economy model will only be successful when it is supported by business concepts. One of these concepts is "product as a service", in which the companies do no longer sell products but are paid for the service (or function) they offer. The circular economy model, aided through the use of digitalization, has driven business model innovation across all industries, in particular the as-a-service business models.

The business model innovation is also stimulated by changing consumer demands and expectations. People do not want to own products; they want a service with a solution for a problem or a desire when and where it is needed. This is caused by a value shift in the consumers' attitude, being more willing to share products as a choice of principle or for economic reasons (it can be cheaper to buy a service than to purchase the product). This evolution is called the "sharing economy" and is developing as a major, long-run social trend.

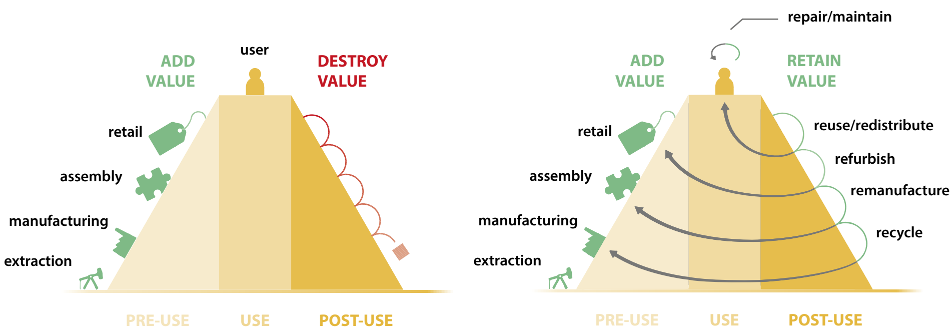

Figure 3.8 Value Hill in the linear economy versus circular economy. Adapted from [23]

4.7 Design for Reuse and Repurposing (DfRR)

Reuse of products (or parts) can be accomplished in several ways:

- ✓ Reuse for the same purpose; for example, certain durable packaging can be used multiple times. Alternatively, products can be collected after use by their producers and, after a quality check or cleaning step, turned back into the cycle.
- ✓ Reuse for a different function, i. e., repurposing; for example, an empty mustard pot becomes a drinking glass, or a packaging becomes a toy.
- ✓ Reuse of a product by another consumer: Offering unused or after-use products at recycling centers, on e-networks, or in barter clubs can stimulate reuse or repurposing of the product by new consumers.
- ✓ Use or reuse of products by multiple consumers is part of the share economy also known as "peer-to-peer economy". Sharing becomes a socio-economic system stimulating collective consumption. For example, in a rural neighborhood the common purchase of a lawnmower can maximize its use, instead of every single household buying one and it standing most of the time idle. Designing products for multiple consumers may, however, require more stringent specifications, such as making the product more robust as not every user equally takes good care in the use of a product that is not property. It implies the anticipation of a behavioral trait.
- ✓ Reuse by given discarded products a new life on a big scale; for example, foam mattresses become aquaculture substrates to grow plants.

Reuse can be promoted by:

- ✓ Repairing the products when broken. The design needs to allow easy repair. Total part integration or gluing is therefore to be avoided.
- ✓ Incentivizing consumers to repair their products when broken or for buying repairable products. An example is the repair-cafés, where locals get together and help repair on a voluntary basis products of other consumers.

4.8 Design for Repair and Maintenance (DfR – DfM)

An important aspect for the consumers to use their products longer is the ability to maintain and repair them. The designer should be aware that the technician who does the maintenance or repair is not the technician who assembled the product. Communication on the proper maintenance and repair procedures is very important to guide the technician. As products typically consist of multiple parts, and only one part may need repair, the availability of the replacement part must be ensured over an extended period of time.

The designer can get inspired by following ecodesign guidelines:

- ✓ Design the product for easy cleaning. An example is fruit juice machines, which are typically very difficult to clean. There are a lot of parts that can have very small nooks and crannies that are hard to clean.
- ✓ A modular design allows for easy replacement of broken parts.
- ✓ Map out the most critical/weak parts and group them into a replaceable module.
- ✓ Create digital product tracking, to support the maintenance.

4.8.1 Dilemma: Repair versus New Product

Figure 4.5 To repair or purchase a new product is a sustainability dilemma

An interesting question is: "Can the ecological impact of repaired products ever be lower than that of new products?" and should facilitate the decision of: "Purchase a new refrigerator that is much more energy-efficient or repair the old one?". These questions have no straightforward answer and depend on many variables. The production of a new refrigerator generates ecological impacts, but how much better they are than the more energy-consuming older version depends on the age, usage, and function, to find a meaningful answer.

Researchers [24] studied the total energy balance (including use time) of 25 products in eight different categories – furniture, textiles, computers, electric motors, tires, appliances, engines, and toner cartridges. Their conclusions:

- ✓ For products with a long life span that use no energy or consumables, such as furniture and textiles, remanufacturing can lead to an environmental gain, especially by saving on materials.

- ✓ For products with a major energy demand during use in relation to the energy required for the materials' production, production, and assembling of the product, repair does not always provide an environmental advantage; for example, retreaded tires that have a somewhat higher roll resistance than new ones and thus can augment fuel consumption of a car. New insulation technology in refrigerators can significantly reduce their energy consumption.
- ✓ For products that have a low energy consumption during use, such as printers, it is advisable to focus on prolonging the life span [25].

It is the designer's challenge to calculate the optimal use time of energy-consuming products in relation to potentially novel technological offerings for answering the question: "What is environmentally beneficial: driving a long time an older car or frequently buying a new one having less fuel consumption and lower emissions?". It should be noted that in the case of cars the fuel benefit is often nullified by producing heavier cars from adding additional functionalities. Alternatively, even if technology over the years allowed for significantly better fuel efficiency of the individual car, the total ecological impact of the sheer number of cars far outstrips the positive contributions.

4.9 Design for Remanufacturing or Refurbishing (DfRM – DfRF)

There are several ways to ensure materials, parts, and products remain in use as mentioned above. In addition, products can be collected by their producer or other companies to be upgraded and refurbished. For example, a smartphone can be upgraded or resold or rented.

In Chapter 8 new business models that stimulate manufacturers of products to keep their products in a loop system via remanufacturing or refurbishing are discussed.

Product–service business models are a very powerful strategy within the circular economy model. The value chain loop closure is almost 100% ensured. Products, part, and materials remain as capital investments in companies and encourage a more prudent use of scarce resources. It is therefore in the interest of the producers that the products can be refurbished and remanufactured quickly and easily. An additional feature is ensuring that the reverse logistics functions well and that consumers/customers are given sufficient incentives to participate.

Some "design for remanufacturing" guidelines are:

- ✓ Make products modular so an easy upgrade and customization can be provided, meeting the different needs of the user.
- ✓ Product quality and reliability is very important, because the less maintenance is needed and the longer the products last, the lower the costs the company has.

4.10 Design for Recycling (DfR)

Besides extending the life span of products for use, a more popular discussion topic is recycling. Recycling is considered as the option for closing the loops in the circular economy model for materials and chemicals. The set of guidelines to promote the closing of the materials and chemicals flow is called “design for recycling” (DfR).

DfR is ever more important in a circular economy model to become the standard mode of operation. Tracking, collection, identification, separation, and reworking of products, parts, or materials either mechanically or chemically are the focus of legislation and extended product responsibility. For 2025 and 2030, the EU has set recycling targets and “product take-back” rules (extended product responsibility (Section 9.3.2 in Chapter 9)) for cars, packaging, electric appliances, and electronic devices. This system creates a reverse logistics of products and materials that makes the design of recycle-friendly products from recyclable materials crucial to keep costs and the overall environmental footprint low [26, 27].

For the designer it becomes imperative to understand the different recycling processes of different products and materials. Only then can products have a maximum chance of being recycled. A designer is also expected to have a forward-looking vision on possible future and ideal recycling processes for the products designed today. A designer is challenged to look at products as a collection of materials that after use need to be capable of becoming the feedstock for a new product in an economic and environmentally attractive way. This approach is fully aligned with the circular economy model.

A good collaboration with recycling experts is recommended for designing a recyclable product. A collaboration between the different value chain stakeholders – raw material producer, manufacturers, converters, distributors, brand owners, consumers, recyclers – makes it possible to create a closed loop of products and materials. The key to success, however, is the willingness of these stakeholders to share their burdens and truly collaborate. Many hurdles need to be overcome to make this possible. Competition, intellectual property, profit and loss, and existing market share are a few potential barriers for which new ways of organizing and structuring collaborations need to be sought.

The most important DfR guidelines are:

- ✓ Use recyclable materials. This means that the material should be recycled in an economically acceptable way including effective and efficient collection and recycling schemes.
- ✓ Keep the material flow pure. In the circular economy model materials need to be recycled not once but over and over again. In the process, substances can accumulate and contaminate so that materials need expensive purification steps. For example, food-grade plastics need to qualify against certain criteria of health and safety.
- ✓ Use as few different materials as possible. The fewer types of materials used, the more economically interesting to start collection and recycling facilities.

5.2 Ecodesign Tools Based on Product Life Cycle Thinking

Next to strategy tools that help set a sustainability direction for companies and organizations, there are plenty of tools that support the actual product development process.

These ecodesign tools are used to:

- ✓ Screen existing products as to their ecological impact and work out an optimized redesign
- ✓ Develop new products with minimal ecological impact over their entire life cycle
- ✓ Integrate the principles of a circular economy model in the design early on
- ✓ Verify during and after the development process the correctness of choices made

All ecodesign tools are based on the concept of life cycle thinking (Figure 5.5). Each stage of the product's life cycle is deliberated, from mining, extraction, or harvesting of the raw materials to after-use handling. At each stage, the in- and outputs of materials and energy are reviewed, including emissions in air, water, and soil and the amounts of post-use product handled and kept in the loop and how much is dissipated.

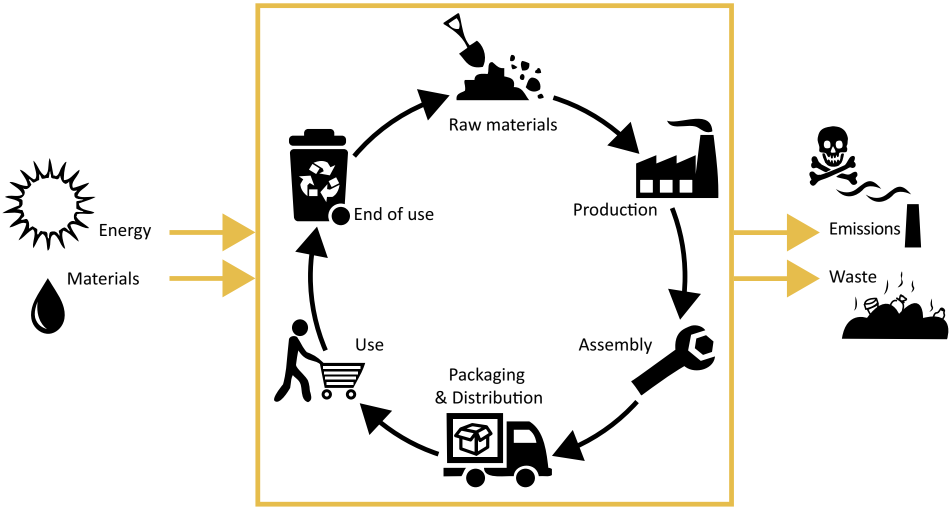

Figure 5.5 A simplified representation of a product life cycle

Two groups of ecodesign tools are distinguished as either quantitative or qualitative in focus. All tools support the product development process and the final choice for a product design.

The quantitative tools are based on measurements, databases, and extensive calculations but can only provide indicative results on the ecological impact and overall sustainability of a product. An awareness of the underlying methodologies and data quality (accuracy, precision, time) used is important to avoid overinterpretations. Nonetheless, quantitative "what-if" results, ratios of variables, and comparing numbers obtained with the same underlying assumptions/model are very useful in relative terms to steer the development, even if their accuracy is questionable. Qualitative tools are typically based on rules of thumb for screening purposes of the existing products or during new developments. They may relatively quickly indicate opportunities for improvement or can inspire the designer for creatively implementing solutions aligned to a circular economy model.

The ambition of many researchers is to develop a tool to come up with a single measure that captures the circularity level or ecological impact over the life cycle of a product. But measuring and expressing this complexity in figures is an impossible task and can even lead to incorrect conclusions. The application of universal rules of thumb in the design process invites innovative design decisions. Therefore, the use of qualitative tools is preferred during the ecodesign process. The assessment of the rules of thumb can be substantiated by the quantitative tools.

5.2.1 Quantitative Tools

Quantitative tools are all based on measurable data that is translated into various damage impacts, such as greenhouse effect and depletion of raw materials. The environmental damage profile of a product, process, or service is then estimated on the basis of weightings and assumptions, in order to gain an insight into the environmental hurdles that can subsequently be tackled in a redesign.

5.2.1.1 Life Cycle Assessment (LCA)

A life cycle assessment (LCA) tool evaluates the ecological stress related to a product, process, or activity. The tool provides a systematic procedure for the identification and quantification of materials, energy, emissions, and dissipation throughout the product's life cycle. Eventually, the findings make it possible to assess their impact on the environment in numbers. The LCA can identify stages in the product life cycle that may be made more environmentally friendly or enables a comparison of several products with similar functions as to their relative sustainability.

The LCA studies examine the full life cycle of a product: mining, extracting, or harvesting raw materials, production of bulk, technical, or specialty materials, the fabrication and assembly of the product, transport and distribution, use, maintenance, reuse and after-use handling, and any other activity that has a bearing on the product. For example, certain studies include levels of child labor, or amounts of forest used or destroyed from mining rare earth elements.

The LCA process is sometimes described as cradle to grave, cradle to gate, gate to gate, or cradle to cradle to indicate certain restrictions set on the assessment. Cradle to grave typically indicates from raw material to product waste (no after-use handling included), Implementation of ecodesign in the product development process may also need a broad system design approach, especially when the aim is to develop innovative products instead of a simple redesign.

6.1 The Design Process

During the design process several stages are considered. They run from the problem definition and the objective setting to the final market introduction of the novel product. Figure 6.1 shows the essential stages of the design process.

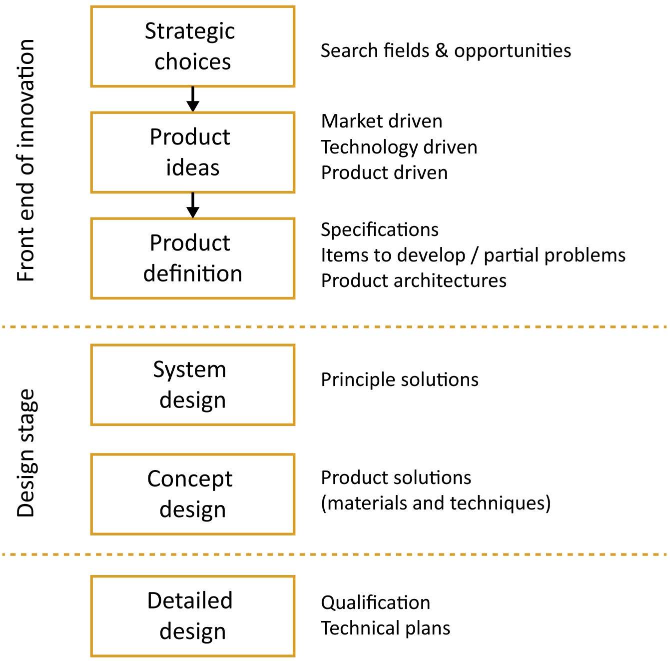

Figure 6.1 The essential stages of the design process

Every stage is an iterative process in itself resulting in a final decision before going to the next stage (Figure 6.2). The decision relates, among others, to an assessment of the innovation potential, to solutions that may meet the needed product specifications, to the fit of the product with a circular economy model, and to the technical capabilities and expertise available and required.

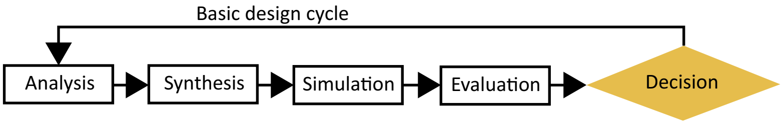

Figure 6.2 The iterative process in each stage of the design process

At each stage all available ecodesign tools (Section 5.2 in Chapter 5) can be used for inspiration and to support the advancement of the project. Ultimately, the newly developed product should score significantly better with a high factor.

6.1.1 Stage 1: Strategic Choices

The first step in a design process aims at identifying potential application spaces and opportunities for innovation at a strategic level. Several approaches are possible:

- ✓ Analyze the existing situation (e. g., strengths, weaknesses, opportunities, threats (SWOT) analysis [1]).
- ✓ Identify and explore options in existing or potential new markets (e. g., Ansoff matrix [2]).
- ✓ Explore the principles of a circular economy model including alternative business models.

The outcome of this stage defines the strategic choice of organizations. The strategy includes ecodesign as an essential part of the strategic implementation plan. This is a critical element as continuity in strategy keeps the focus and direction to ensure progress on delivering the objective. The cost and effort to include ecodesign principles from the beginning is relatively small compared to the final impact of the project and overall costs (Figure 6.3). Integrating ecodesign at a later stage will demand more time, efforts, and costs with the consequence of a lower impact of the efforts. At a later stage many decisions that have already been taken are difficult to reverse. The strategic choice to keep open as many options as possible during the consecutive design stages can help to implement innovative changes. A certain adaptability and agility spirit can be important – while keeping the strategic direction – because the internal and external operational conditions of organizations can change over the years quickly. For example, making the choice for a combined products–services approach may enable a great ecological advantage that is in line with the principles of the circular economy model. When the ecodesign principles are introduced later in the design process it is hard to find a good compromise with the other design criteria. Furthermore, it can take much more effort to implement the ecodesign principles if work has to be redone even when only a small change needs to be made; for example, selecting another material supplier whose product can fulfill the need to lower the ecological impact.

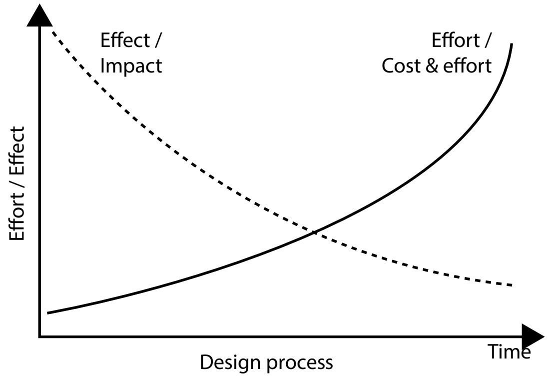

Figure 6.3 Effect–effort curve. Overtime it pays to start early in the design process to think sustainably and apply the ecodesign principles in the product development workflow

The appropriate ecodesign tools for this stage are:

- ✓ Those used to provide insight into the ecological opportunities for an organization's strategy (Section 5.1 in Chapter 5)
- ✓ Tools that can be useful to identify the environmental bottlenecks of an existing product and suggest opportunities for improvement. Both qualitative and quantitative tools can be used, such as LCA, LiDS wheel, Eco-star, lists of rules of thumb, and specific rules of thumb for the circular economy (Section 5.2 in Chapter 5)

6.1.2 Stage 2: Product Ideas

Provided a strategic choice is made and the objective is defined, ideas for potential solutions can be sought. Several approaches and methodologies can be followed to generate ideas. Creativity workshops, brainstorming sessions, and many more are structured approaches that bring people together to reflect on the challenges and to provide workable ideas with a possible perspective for realization and implementation. One of the brainstorm techniques used to solve complex technical problems is *teoriya resheniya izobretatelskikh zadatch*, better known by the acronym TRIZ [3]. The TRIZ theory was conceived by Genrich Altshuller, a Russian engineer, while working at the "invention inspection" department of the Soviet Navy in 1946 [24]. By extensive research on hundreds of thousands of inventions, he observed generalizable patterns in the nature of inventive solutions and distinguishing characteristics of the problems that these inventions had overcome. These were later summarized in 40 principles based on the concept of technical contradictions. These contradictions relate to the fact that during a product design evaluation, more of one beneficial property may actually bring on something else that is less desirable. For example, designing a car tire for retreading actually increases the overall tire weight, which directly affects an increase in fuel consumption and is undesirable. Conventional solutions typically make a "trade-off" between the two design criteria, which does not require an inventive step. The TRIZ approach would resolve the contradiction by developing inventive technical solutions that provide, in the case of the tire example, a lightweight retreadable tire in different ways. These 40 principles are put in a matrix of contradictions, with each matrix cell representing the most frequently used invention to resolve the contradiction [4].

Besides the generation of potential solutions and approaches to achieve the objective, a structured effort can help to better define or improve the objective setting and formulation. The synthesis of all this information creates the basis for a common understanding (everybody on the same page) and the formulation procedure that orients all involved actors in the same direction. Clarity of purpose in the process is essential to avoid misunderstandings and wasting time and money.

6.1.3 Stage 3: Product Definition

Next, the specific product needs are determined. This can include the definition of the conceptual product architecture and the product performance. Optimally, it can involve understanding customer needs and requirements before any work on the product itself is undertaken. When determining the design tasks all functional, production, material, economic, ergonomic, ethical, safety, security, legislative, and ecological impact aspects need to be clarified and defined in a coherent manner.

Ecodesign projects include the entire system, which makes the design process more complex. Each stage of the product life cycle is examined in detail for exploring and identifying the best possible solution that contributes to reducing the ecological impact factor. The designer has a demanding job not to resort to simplistic choices that just "greenwash" the product. In the circular economy model the entire value chain is examined. Communication between the different stakeholders becomes critical to ensure their continued support and contributions to the ecodesign project. The designer has a key position to bring the stakeholders together and translate their wishes into specifications. The measurability and the detailed specifications are important starting points to evaluate and optimize progress in the next stages.

6.1.4 Stages 4, 5, and 6: System, Concept, and Detailed Design

In these stages of the ecodesign project the actual product design is further worked out. In the system design stage possible solutions are sought to fulfill the main functional requirements of the product. It includes bringing together all the elements that enable the final fabrication. In relation to the desired and expected innovation level (Figure 6.4), the implementation of the ecodesign criteria varies from the consideration of the ecodesign guidelines to the understanding of the entire system.