THESIS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

# Circular design through co-creation

Exploring perspectives and future directions for design in a circular economy

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# Abstract

In the efforts to stimulate sustainable development, the circular economy aims to establish 'closed-loop' flows of resources in a way that enables businesses and society to reap benefits from maintaining products, components and materials at their highest utility and value, while simultaneously reducing the generation of waste. Designing for a circular economy will require designers to, more than ever, anticipate how artifacts function and change over time and conceptualise the entire lifecycle (including the design, production, use and end-of-life phase) in a coherent and holistic way. This implies that design efforts, to an increasing extent, will have to address the interaction and collaboration between companies and other stakeholders that need to work together to enable the extended utilisation and recirculation of resources. To date, there have been few studies examining the implications of the circular economy for the practice of design.

Therefore, the thesis investigates the implications of the circular economy concept for designers and design practice, and further examines the role of stakeholder collaboration and co-creation in supporting design for a circular economy. The findings indicate that the circular economy is a multi-faceted challenge that expands the scope of design projects, drives the integration of new knowledge areas in the design process, affects the role of designers and agencies in practice, and demands further interdisciplinary collaboration and co-creation. A challenge for designers in the context of circular design is to purposefully plan when, how, and to what extent stakeholders are involved in the design process. In this regard, co-creation approaches are found to be important to enable joint learning about circularity, identify opportunities for shared value creation in the context of the circular economy, and promote collaboration throughout supply chains and industries. Generative toolkits such as the card-based design tool 'Cards for Circularity' presented in this thesis can help to stage discussions on circular strategies, align perspectives in a multi-disciplinary and multi-stakeholder context to foster better collaborative practices, and support a holistic view on circular-oriented innovation by distinguishing the relevant parameters in circular systems.

To conclude, the findings of this thesis contribute to a better understanding of how the concept of a circular economy is implemented across design practice and identifies pathways to further advance circular design. The thesis is relevant for design practitioners, researchers, and curricula for the growth of circular design theory and the development of appropriate design methods, tools, and guidelines.

Keywords: Circular Economy, Circular Design, Design for Sustainability, Co-creation, Prototyping, Design practice

## Sammanfattning

Den cirkulära ekonomin strävar efter att skapa en ‘sluten krets’ för resursflöden, där produkter och material används på bästa sätt för att minska avfallet och gynna både företag och samhället. Att designa för en cirkulär ekonomi kommer att kräva av designers att i högre grad än tidigare förutse hur artefakter fungerar och förändras över tid och att konceptualisera hela livscykeln (inklusive design, produktion, användning och slutet av livsfasen) på ett sammanhängande och holistiskt sätt. Detta innebär att designinsatser i allt större utsträckning kommer att behöva hantera interaktionen och samarbetet mellan företag och andra aktörer för att möjliggöra utökad användning och återcirkulation av resurser. Hittills har det varit få studier som undersökt implikationer av den cirkulära ekonomin för designpraktiken.

Därför undersöker avhandlingen konsekvenser av konceptet cirkuläritet för designers och designpraktiken samt undersöker hur samarbete och samskapande med olika aktörer kan stödja design för en cirkulär ekonomi. Resultaten indikerar att den cirkulära ekonomin är en utmaning med många aspekter som utvidgar omfattningen av designprojekt, driver integrationen av nya kunskapsområden i designprocessen, påverkar designers och byråers roll i praktiken samt kräver ytterligare tvärvetenskapligt samarbete och samskapande. En utmaning för designers inom ramen för cirkulär design är att medvetet planera när, hur och i vilken utsträckning aktörer involveras i designprocessen. I detta avseende har samskapande metoder visat sig vara viktiga för att möjliggöra gemensam inlärning om cirkularitet, identifiera möjligheter till skapande av delat värde inom ramen för den cirkulära ekonomin samt främja samarbete genom hela värdekedjor och industrier. Verktyg med generativt syfte, exempelvis det kortbaserade verktyget ‘Cards for Circularity’ som presenteras i denna avhandling, kan underlätta och främja diskussioner om cirkulära strategier. Dessa verktyg kan även hjälpa till att förena olika perspektiv inom miljöområdet och sammanföra aktörer med olika kunskap för att främja ökat samarbete. Dessutom bidrar de till att stödja en helhetsbild av cirkulär innovation genom att identifiera och särskilja relevanta parametrar i cirkulära system.

Sammanfattningsvis bidrar resultaten från denna avhandling till en bättre förståelse för hur begreppet en cirkulär ekonomi implementeras inom designpraktiken och identifierar vägar för att ytterligare främja cirkulär design. Avhandlingen är relevant för designpraktiker, forskare och läroplaner för utvidgning av den cirkulära designteorin och utvecklingen av lämpliga designmetoder, verktyg och riktlinjer.

Nyckelord: Cirkulär ekonomi, Cirkulär design, Hållbar design, samskapande processer, prototyputveckling, designpraktiken

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# Terminology

| | |
|---|---|
| Circularity | A term referring to the degree or the proportion of resource flows with circular characteristics |
| Circular economy | An industrial system that aims to establish cyclical flows of resources and keep resources at their highest utility and value at all times |
| Co-creation | Any act of collective creativity |
| Co-design | Acts of collective creativity between designers and people who are not trained in design as a part of a design process |
| Design | The application of intent and the process through which people create material, spatial, visual and experiential environments |
| Designer | Anyone who performs design |
| Design tool | An object, form of media or system that supports the act of designing, or extends the designers capability to do so |
| Design method | A formalized representation of a design activity that functions as a mental tool to support designers to achieve a certain goal, in relation to certain circumstances and resources available |
| Design process | A series of abstracted phases and iterative steps that describes the development of an artefact or solution in which the degree of abstraction is gradually reduced in order to fulfill internal or external requirements or specifications |
| Design strategy | A plan in which design stages and activities are executed to achieve a certain goal |
| Innovation | The process of translating an idea into a novel physical artefact, process, or system which has a social, commercial, artistic or scientific purpose |
| Stakeholder | An individual or an organization who can affect, or be affected, by an organization, strategy, product or project |
| Supply chain | The entire chain of activities from the perspective of all actors involved that are needed to bring the artefact from conception to the final consumer |
| Value chain | The chain of activities from the perspective of an individual organization that are performed to bring an artefact from raw material to final embodied state, where each step in the chain represents a value activity that adds value to the final artefact |
| Value network | A network of actors which interact and collaborate to create, distribute, and capture value collectively |

# Acronyms

| | |
|---|---|
| CE | Circular economy |
| CBM | Circular business model |
| CBMI | Circular business model innovation |
| CFC | Cards for circularity |
| COI | Circular-oriented innovation |
| DfS | Design for Sustainability |
| DfD | Design for disassembly |
| EoL | End of Life |
| LCA | Life cycle analysis |
| PSS | Product-service system |
| RtD | Research through Design |
| PAR | Participatory action research |

# List of appended papers

## Paper A

Dokter, G., Thuvander, L., & Rahe, U. (2021). How circular is current design practice? Investigating perspectives across industrial design and architecture in the transition towards a circular economy. Sustainable Production and Consumption, 26, 692–708. https://doi.org/10.1016/j.spc.2020.12.032 [Published]

*Contribution: Dokter planned the study with input from Thuvander and Rahe. Dokter performed the data collection and analysis and wrote the paper. Thuvander and Rahe reviewed the paper.*

## Paper B

Dokter, G., Cohen, J., Hagejärd, S., Rexfelt, O., & Thuvander, L. Mapping the practice of circular design: A survey study with industrial designers and architects in the Netherlands and Sweden. [Submitted]

*Contribution: Dokter planned the study with support from Thuvander and Rahe. Dokter collected the data. Dokter and Cohen performed the data analysis with input from Thuvander, Hagejärd, and Rexfelt. Dokter and Cohen wrote the paper with input and support from Thuvander, Hagejärd, and Rexfelt.*

## Paper C

Dokter, G., Boks, C., Rahe, U., Wouterszoon Jansen, B., Hagejärd, S., & Thuvander, L. (2023). The role of prototyping and co-creation in circular economy-oriented innovation: A longitudinal case study in the kitchen industry. Sustainable Production and Consumption 39, 230–243. https://doi.org/10.1016/j.spc.2023.05.012 [Published]

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## Paper D

Dokter, G., van Stijn, A., Thuvander, L., & Rahe, U. (2020). Cards for circularity: Towards circular design in practice. IOP Conference Series: Earth and Environmental Science, 588(4). https://doi.org/10.1088/1755-1315/588/4/042043 [Published]

*Contribution: Dokter and van Stijn planned the study with input from Thuvander and Rahe. Dokter and van Stijn developed the tool used for the data collection. Dokter performed the data collection and analysis. Dokter led the writing of the paper with contributions of van Stijn. Thuvander and Rahe reviewed the paper.*

**Paper E**

Dokter, G., Wouterszoon Jansen, B., Thuvander, L., Rahe, U., & Duijghuisen, J. (2022). Reflections on the use of a card-based circular design tool in design education. IOP Conf. Ser.: Earth Environ. Sci. 1078 012057. https://doi.org/10.1088/1755-1315/1078/1/012057 [Published]

*Contribution: Dokter and Wouterszoon Jansen planned the study and developed the tool for the data collection with support from Duijghuisen. Dokter and Wouterszoon performed the data collection and analysis with support from Thuvander and Duijghuisen. Dokter led the writing of the paper with contributions of Wouterszoon jansen. All authors reviewed the paper.*

## Additional publications

Dokter, G, Hagejärd, S., Thuvander, L., & Rahe, U. (2020). Co-creation – a facilitator for circular economy implementation? A case study in the kitchen industry. In N. Nissen & M. Jaeger-Erben (Eds.), PLATE Product Lifetimes and The Environment 2019 – Conference Proceedings. TU Berlin University Press. ISBN 978-3-7983-3125-9 [Available online]

Hagejärd, S., Dokter, G., Rahe, U., & Femenías, P. (2021). My apartment is cold! Household perceptions of indoor climate and demand-side management in Sweden. Energy Research & Social Science, 73, 101948. https://doi.org/10.1016/j.erss.2021.101948

Hagejärd, S., Dokter, G., Rahe, U., Femenías, P. (2023). “It’s never telling me that I’m good!” Household experiences of testing a smart home energy management system with a personal threshold on energy use in Sweden. Energy Research and Social Science 98. https://doi.org/10.1016/j.erss.2023.103004

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# 1. Introduction

Despite substantial efforts and calls to promote sustainable development in recent decades, illustrated by reports such as 'Limits to Growth' (Meadows et al., 1972) and 'Our Common Future' (WCED 1987), it is apparent that these efforts have not led to appropriate measures or the imagined reductions in negative environmental impacts (Sneddon et al., 2006; Murray et al., 2017). Instead, the global demand for material resources has steadily increased over recent decades and is projected to double by 2050 (Krausmann et al., 2018). In 2005, as little as 6% of all materials processed by the global economy were recycled and contributed to the closing of resource loops (Haas, 2015). As of 2023, 7% of the more than 100 billion tonnes of materials extracted annually are cycled back into the global economy (Circle Economy, 2023). Today, six of the nine planetary boundaries referring to stable and resilient conditions of the Earth system are transgressed, which suggests that Earth is well beyond a safe operating space for humanity (Richardson et al., 2023).

To mitigate the environmental pressure resulting from the continuous extraction and production of materials, and fundamentally resolve issues related to natural resource depletion and waste generation, the concept of a circular economy (CE) has gained increasing attention over the last decade. The ultimate objective of this model is to achieve the decoupling of economic growth from natural resource depletion and environmental degradation (Liu et al. 2009; Xue et al. 2010). The CE has gained substantial traction in politics and industry, as it is seen as a way of implementing sustainable development without limiting economic growth (European Commission, 2020a, 2014a). In a CE, the notion of waste is eliminated by maintaining products, components, and materials at their highest utility and value at all times (Webster, 2015), which can be achieved, for example, through long-lasting design, maintenance, repair, reuse, remanufacturing and recycling (Geissdoerfer et al., 2017).

The European Union has ambitious plans to move towards a CE (e.g., increasing reuse and recycle rates of municipal waste to 65% and reducing landfill production to 10% by 2030; European Commission 2019), yet the realisation of a CE is still in its early stages (Ghisellini et al., 2016; McDowall et al., 2017). This limited progress is often related to technical barriers, for example, consumer products are not correctly designed to support longevity, maintenance, disassembly and reuse (Pheifer, 2017). Other studies indicate that the major barriers for a CE are not technical but rather of a cultural nature, such as limited collaboration across value chains, hesitant company cultures and a lack of awareness and interest by consumers. Moreover, another factor hindering progress is that the CE concept itself is interpreted in different ways by different actors (Blomsma and Brennan, 2017) and is the subject of conceptual and terminological unclarity and debate (Kirchherr et al., 2017; Korhonen et al., 2018). Therefore, the CE approach will not be immune to failures, misuse, ambivalence and greenwashing (Sauvé et al., 2016).

This raises questions about 'what version' of a CE we will see in the near future, and whether the CE can deliver on its promise of addressing environmental concerns and establishing a systemic change in the way we view resources and their lifecycles, or whether it will lead to incremental changes at best with the CE becoming yet another 'buzzword of sustainability' (Kirchherr et al., 2017). It also raises questions about the role of design in the transition to a CE, and how designers can contribute to the development of circular solutions and potentially address the barriers that currently exist.

Notwithstanding the ambivalence surrounding the CE, there seems to be a consensus in academia and politics that design plays an important role in the transition to a CE (De los Rios et al., 2017; European Commission, 2020a). Design, defined as the process through which we create the material, spatial, visual, and experiential environments, has a direct influence on the environmental impact of artefacts such as consumer products and buildings. This view is often supported by the claim that 80% of the environmental impact of products is determined in the design phase (European Commission, 2014b; Graedel et al., 1995).

Yet, for designers, which in this thesis includes both product designers and architects, the CE imposes many challenges that require novel approaches. Designing products and buildings that function in a closed loop of resources requires designers to, more than ever, anticipate how such artefacts might function and change over time and conceptualise the entire lifecycle including the design, production, use and end-of-life (EoL) stage concurrently and coherently. Furthermore, designers are also faced with various non-technical challenges that currently form the major barriers to a CE (Kirchherr et al., 2018; Ritzén and Sandström, 2017; Rizos et al., 2016). After decades of predominantly operating in silos, the CE increasingly challenges companies to collaborate on a systemic level (Pieroni et al., 2019). After all, the successful implementation of a CE does not rely on individual actors, products, or services becoming circular but rather on the design of systems that are circular (Konietzko et al., 2020a). Such circular systems rely on the combination of (1) the circular design of products in line with the principles of slowing and closing resource loops, (2) business models that incentivise and capture value of the extended utilisation and recovery of products and materials, and (3) supply chains and value networks that work together to enable the above and maximise shared value creation.

Hence, the success of design efforts towards a CE relies to a great extent on establishing resilient collaborative value networks in which partners work together to benefit from the extended utilisation and circulation of products and resources. This draws attention to the potentially meaningful role that designers (could) play in connecting value- and supply-chain actors, fostering collaboration for CE-oriented innovation (COI), and the co-design of circular value propositions within operational and increasingly complex design processes. Accordingly, it is key to not solely focus on the design of physical objects but rather on the design of the stakeholder network and its relationships (Pedersen and Clausen, 2019).Furthermore, collaboration is not only important during the design stage, but also during and beyond the lifecycles of products and buildings. For design practice, this represents both a challenge and an opportunity to become more involved across value chains and throughout the lifecycles of artefacts.

Collaboration is nothing new to the design process, which has always been a dynamic process featuring teamwork, stakeholder interaction and the balancing of (often conflicting) demands. In recent decades, responding to the growing complexity of global challenges and sociotechnical systems, the scope of design has moved from object-centric thinking to system-based design approaches (Ceschin and Gaziulusoy, 2016). Designers, to an increasing extent, perform strategic activities such as developing strategic visions, facilitating dialogues between actors, business development, and utilising participatory design approaches to stimulate inclusive and democratic design processes that lead to holistic solutions. The role that designers play as facilitators of collaborative design processes has been widely investigated in design research (Manzini, 2009) and, for example, in the context of whole system (Charnley et al., 2011) and participatory design (Luck, 2007) but to a limited extent in the context of the CE. The traditional object- and user-centric design approaches emphasising designer skills appear to fall short in tackling global and systemic challenges, and have to be transformed into community-driven, co-creative, bottom-up collaborations with expert knowledge throughout domains (Meyer and Norman, 2020; Sanders and Stappers, 2008).

Thus far, previous studies regarding designing for a CE have focused on developing methods, tools and frameworks to support circular design and investigated the changing roles and competencies required of designers in a CE (Andrews, 2020; Bocken et al., 2016; De los Rios et al., 2017; den Hollander et al., 2017; Mestre and Cooper, 2017; Moreno et al., 2016; Sumter et al., 2018; Wastling et al., 2018). Another stream of literature has investigated the potential of linking sustainable design theory and design thinking with circular business model innovation (CBMI) and COI (Baldassarre et al., 2020a; Geissdoerfer et al., 2016; Guldmann et al., 2019; Santa-Maria et al., 2022a).

However, there has been a lack of empirical investigation into how the CE concept is currently interpreted and implemented in practice by designers and what they experience as the main challenges of designing for a CE. Furthermore, while the importance of collaboration and co-creation in design and innovation for a CE is apparent, there have been limited empirical studies aiming to better understand the role of co-creation and co-design throughout design and innovation towards a CE and how these processes can be further guided and supported.

## Aim and research questions

The overall aim of this thesis is to contribute to a better understanding of how the CE concept is currently implemented in design practice and investigate ways of advancing circular design in practice. This aim was realized partly during the licentiate thesis (Dokter, 2021), and continued into the work carried out in the context of this thesis. The thesis sets out to first examine how the concept of a CE is currently interpreted and operationalized within design practice, focusing on the disciplines of industrial design and architecture. Next, the thesis proceeds to investigate the role of designers in fostering collaboration for a CE and the role of co-creation in supporting design for a CE. Lastly, the thesis explores how co-creation as a part of design for a CE can be further leveraged and supported. To address the aims of the thesis, the following four research questions are formulated:

1. How is the concept of a circular economy currently interpreted and operationalised within design practice?

2. What factors are currently supporting or hindering circular design in practice?

3. What is the role of co-creation in supporting design for a circular economy?

4. How can co-creation as a part of design for a circular economy be further supported?

## 1.1 Research scope

### 1.1.1 Research context: the Circular Kitchen

The starting point for this thesis work was the research project 'The Circular Kitchen' (CIK). The project was a collaboration between two universities (Chalmers University of Technology and Delft University of Technology) and stakeholders in the kitchen industry from both the Netherlands and Sweden, including kitchen furniture manufacturers, appliance manufacturers, and housing developers. The CIK project aimed to develop a market-ready kitchen solution based on CE principles with a potential for scalability exemplified through demonstration kitchens placed in the Netherlands and Sweden.

The project was motivated by the pressing environmental concerns within the kitchen industry. Kitchen furniture and appliances contribute substantially to the environmental impact of domestic buildings (Hoxha and Jusselme, 2017). Kitchens are frequently refurbished over the lifetime of a building, and it is not uncommon that kitchen furniture and appliances are replaced far before they have reached their expected lifespan. In Sweden, premature replacement of kitchen furniture and appliances has been estimated to contribute as much as 57% to the overall climate impact of interior renovations in owner-occupied apartments (Femenías et al., 2016). In the EU, approximately 25% of the annual 10 million tonnes of discarded furniture consists of kitchen furniture, with only 10% being recycled and the majority being incinerated or landfilled (Forrest et al., 2017).

In the prevailing linear business models adopted by kitchen manufacturers, the sale and installation of kitchen furniture often mark the end of their involvement (other than a limited warranty on damaged furniture). These challenges can be to some extent associated with the design and construction of kitchens; contemporary kitchen furniture often comprises fibreboards such as medium-density fibreboard (MDF) or chipboard with a limited lifespan and is not designed for lifetime extension or multiple use cycles (e.g., they are difficult to repair or disassemble) (Forrest et al., 2017), therefore representing limited value after use and are frequently destined for energy recovery. Thus, opportunities exist to incorporate CE principles to capture value of lifetime extension and resource recovery and provide services to enable refurbishment, recovery, reselling, and recycling (Ollár et al., 2020).

Considering the mentioned challenges rely on the combination of the design of kitchens, the structures of business models, and the way that the current supply chains operate, the project adopted a systemic perspective and focused on product-level innovation (of kitchen furniture and appliances) and simultaneous work on value network configurations and circular business models to shift towards a circular system. The project pursued cooperation with relevant stakeholders and adopted a design-driven approach emphasizing co-creation, prototyping, experimentation, and practice-based research in real-life settings. From a research perspective, the CIK project, thus provided an opportunity to examine a circular-oriented innovation project first-hand, which spanned four years, involved multiple stakeholders, and considered both the design and business context. As a result, the project sparked a research interest to further investigate the concept of a CE, the practical implications of designing solutions for a CE, and the role of co-creation in the context of a CE. Although the research provided many relevant insights on the topic of resource circularity in the kitchen industry and the design of kitchens in line with CE principles, the kitchen as an artefact or space is not taken as the central theme or object of study in this thesis. Instead, the CIK project was used as a frame and context to further investigate the implications of design for a CE, and the role of co-creation and designers in a CE (see Figure 1).

The research context of the kitchen naturally connected to both the fields of industrial design and architecture, and the disciplinary background of the researchers in the project was both architecture and industrial design. A kitchen is a space in which products are used and (ideally) well-integrated (e.g., kitchen appliances, utensils, furniture) and where factors such as ergonomics, usability, functionality, and human interaction are of importance. A kitchen is also a building component within the overall structure of a building and a space where factors such as movement, workflow, well-being, and human interaction closely relate to the planning and spatial characteristics of the kitchen. Hence, integrating the considerations of both disciplines is beneficial to ensure a holistic approach towards solutions that aim to promote circularity. For instance, a dishwasher or oven can be designed in a way that components are accessible and modular so that it is principally easy to maintain, repair, or replace components when needed. Yet, if these appliances are integrated or placed poorly within the kitchen as a space, the potential for such interventions to occur in practice can be severely inhibited.

In the Swedish CIK project, three doctoral students participated with each having a different

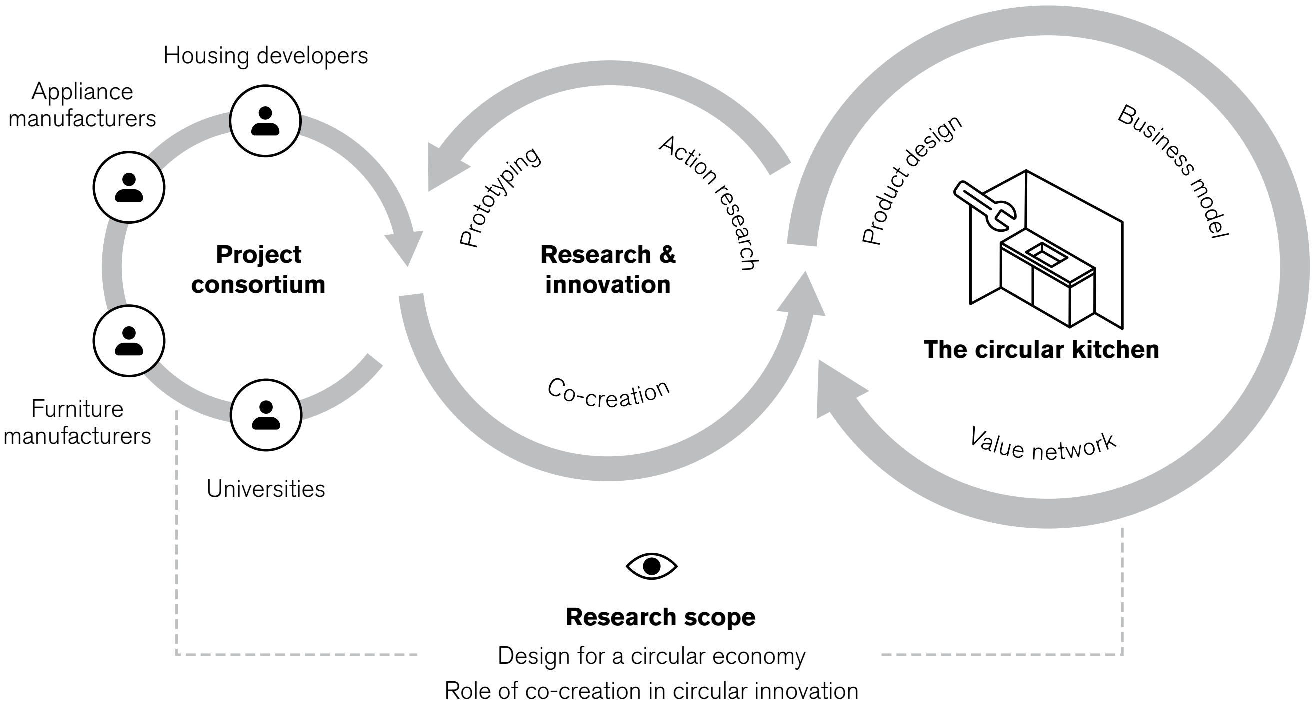


*Figure 1.* The circular kitchen project is a frame for the research conducted in this thesis.

research scope and focus. My role in the project mainly focused on contributing to and facilitating the development process of the circular kitchen concept and prototypes, and the research focused on examining the practical implications of designing for a CE and the role of collaboration and co-creation with industry stakeholders (particularly kitchen and appliance manufacturers). Another doctoral student focused on the influence of spatial factors and adaptive capacity in circular housing design by studying the kitchen, and how the value chain of construction (e.g., housing developers) can be steered towards circularity (Ollár et al., 2022, 2020). The third doctoral student focused on the perspective of households and how practices and resource use within homes can shift towards circularity, focusing more on the perspective of the user towards circular value propositions within the context of the kitchen (Hagejärd et al., 2023, 2021, 2020). In the Dutch CIK project, two doctoral students participated, one focused on design guidelines and tools for circular building components, and dedicated CE-LCA models for circular building components (van Stijn et al., 2022a, 2022b, 2021; van Stijn and Gruis, 2019). The other had a strong focus on the development trajectory of the circular kitchen in the Netherlands, focusing on stakeholder cooperation and decision-making in the development of circular building components (Wouterszoon Jansen et al., 2022b) and modelling the economic performance and lifecycle costs (Wouterszoon Jansen et al., 2022a, 2020). The different students collaborated throughout the circular kitchen project, both in the innovation trajectory and the research efforts, which resulted in multiple publications.

Historically, the context of kitchen design in Sweden provides interesting examples where the synthesis of industrial design and architecture can be well-observed. From the 1940s, the Hemmens Forskningsinstitut (The Swedish Home Research Institute) concerned itself with improving domestic work and life conditions, deploying and developing meticulous research and design methods to shape national standards and norms for the design of kitchens and utensils which are still relevant today in Sweden. One can trace early forms of user-centred design with considerations for ergonomics, ethnography, iterative prototyping, and user testing, while also addressing the architectural layout and spatial aspects of the kitchen (e.g., investigating how people move in kitchens through motion studies and how space is adapted to people through ergonomic studies) (Göransdotter, 2020). Figure 2 shows examples of these types of research focusing on the assessment of kitchen appliances and motion studies.

Given the context of this research, a potential was identified to investigate the topic of circular design both within the domains and from the perspectives of architecture and industrial design. The following sections will explain this focus in further detail and elaborate on why the chosen scope of both design disciplines contributes to research within the context of circular design.

### 1.1.2 Situated between the fields of architecture and industrial design

The research in this thesis is positioned within the fields of architecture and industrial design, two distinct yet interrelated design disciplines that hold significant importance in enabling the design of products and buildings in line with CE principles (European Commission, 2020a). In this thesis, design practice is considered the practice of an individual whose occupation is that of a designer, and a design practitioner or design professional can be defined as an individual whose occupational role is that of a designer. 'Design' can be defined as the process through which people

*Figure 2.* Research by the Hemmens Forskningsinstitut assessing the performance of kitchen machines (left) and performing motion studies of two people in a test kitchen (right). Image credits: Sundahl, Sune, ArkDes; Studio Granat, Nordiska Museet.

create material, spatial, visual, and experiential environments ("Montreal Design Declaration," 2017), and both industrial designers and architects can therefore be considered as designers.

Within design practice, there can be considerable differences between the experiences and perceptions of designers across different organisational levels and structures (Björklund and van der Marel, 2019). For example, designers who are directly employed by a product manufacturer, compared to designers in consultancy settings, may be involved throughout more phases of the product development process (from design brief to realization and beyond) and may have a greater influence on those phases. Perceptions and practices regarding circular design and the possibility of practitioners incorporating and engaging with CE principles in their work can depend strongly on their role, position, and type of organization.

It should be noted that other design disciplines are also relevant to investigate concerning design for a CE (e.g., fashion and textile design, interior design), but these are mostly left outside the scope of this thesis as the context of the research (the CIK project) related primarily to the fields of architecture and industrial design.

While architecture and product design are distinct fields, early models for design methods and processes were very similar but diverged in the 1970s in response to criticism from both design theorists and practitioners (Cross and Roozenburg, 1992). According to Alexander (1965), the tree-like problem-solving approach (breaking down the overall problem into sub-problems, sub-sub-problems, etc.) in engineering design was not suitable for architecture and planning. Roozenburg and Cross (1991) emphasised the need to reintegrate design models and advocated for a generalised and integrated model within design education. A reaction to this need was the basic design cycle introduced by Roozenburg and Eekels (1995).

Indeed, one can argue that the disciplines of architecture and industrial design exhibit fundamental differences in terms of competencies, scale, materiality, lifecycle perspective, business contexts, and regulatory constraints. Yet, the CE is an interdisciplinary, systemic, and multi-scalar challenge (Murray et al., 2017) and in pursuit of circular products and a circular built environment, these disciplines share the common aims of closing resource loops and decoupling economic growth from resource consumption. Studying and comparing the two design disciplines despite the differences can provide valuable insights: (1) synergising design perspectives could promote holistic and systemic design approaches towards a CE, (2) investigating approaches and efforts across disciplines can provide a basis for further dialogues and knowledge exchange, and (3) increasing the understanding of the overall advancement of CE practices within design practice.

### Outline of the thesis

The thesis is structured as follows. Chapter 2 provides a background of the theory that is relevant to this thesis. Chapter 3 describes the methodology including the overall research design and utilised methods for the three studies that are included in this thesis (encapsulating paper A-E) as well as a reflection on the chosen research approach. Chapter 4 provides a summary of the findings of the different studies and further elaborates on the results of comparing findings between studies. Chapter 5 discusses the findings in relation to the research questions and previous research. Chapter 6 describes the conclusion and contributions of this research and presents some recommendations for future research. Finally, the five research articles resulting from the different studies are appended.

# 2. Theoretical background

This chapter provides an overview of relevant literature for the scope of this thesis. First, the concept of a CE is briefly introduced and positioned within the field of design for sustainability. Next, the concept of circular design is introduced and elaborated on in the context of industrial design and architecture. In addition, implications of the CE for design practice and the role of designers are described based on the investigated literature. The following section describes circular business models and circular-oriented innovation. Finally, the role of collaboration and co-creation as well as prototyping as a part of CE innovation processes is clarified.

## 2.1 The concept of a circular economy

The industrial systems of today are largely based on a linear model of operation; raw materials are extracted from the earth and are transformed into artefacts such as consumer products and buildings which sooner, or later, will become waste. The principles of such a linear economy have been widely referred to as "take-make-dispose" (Ellen MacArthur Foundation, 2013) and are inherently unsustainable due to the limited availability of finite resources and the continuous generation of waste. Global material extraction rates have increased by 53% over the last two decades (Krausmann et al., 2018), and the extraction and production of materials is an important source of greenhouse gas emissions, of which the majority can be attributed to the construction and manufacturing sector (Hertwich, 2021).

An alternative economic model and industrial system that could potentially address issues related to resource efficiency and waste generation is that of a CE, which concerns the notion of establishing cyclical flows of resources. A CE aims to keep products, components, and materials at their highest utility and value at all times (Webster, 2015) and principally eliminate the notion of waste. While the CE has been popularized in business and policy environments in the last decade, the idea itself is not novel and can be seen as an umbrella concept (Blomsma and Brennan, 2017) which encapsulates and synthesizes a range of pre-existing ideas and principles for closing material loops and reducing the throughput of raw materials and energy (Benyus, 1997; Boulding, 1966; Braungart and McDonough, 2002; Lyle, 1994; Pauli, 2010; Stahel, 2010). According to (Murray et al., 2017), Stahel and Reday-Mulvey (1976) were the first to refer to a closed-loop economy, by drawing from ideas of substituting energy with labour, reasoning that 'it took more labour and fewer resources to refurbish buildings than to erect new ones', which is a principle that holds true for any form of capital – from consumer goods such as mobile phone to buildings (p. 435) (Stahel, 2016).

Although it might not be possible or desirable to capture the CE in a single universal definition due to shifting conditions and the diverse roots of the concept (Blomsma and Brennan, 2017; Kirchherr et al., 2023), the concept can be described as a 'regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling.' (p. 766) (Geissdoerfer et al., 2017). Here, slowing concerns extending the use phase of artefacts, closing refers to recycling, and narrowing refers to reducing the amount of resources needed for a given artefact. The combination of these three overall guiding principles forms a helpful guiding terminology for design and business model strategies in a CE (Bocken et al., 2016). Also central to the CE concept are the taxonomies of circular strategies which have the potential to preserve resource value, also referred to as 'resource value retention options' (Reike et al., 2018). These strategies are often grouped and visually represented in a hierarchy based upon the capacity to which they retain resource value, ranging from the 3Rs (reduce, reuse, recycling), the 9Rs (Potting et al., 2017), up to the 10 Rs (Reike et al., 2018).

These strategies are typically grouped and conceptualised in various R frameworks from the 3Rs (reduce, reuse, recycling), the 9Rs (Potting et al., 2017) up to the 10 Rs (Reike et al., 2018), in which they are positioned in a hierarchy that is based on the extent to which they retain the value of the resources. As an example, it is, in theory, more resource-efficient and less wasteful to keep a chair performing its original function by repairing and refurbishing it, rather than to break it down and recycle the materials (recycling would imply a greater loss of value and would require more energy and resources). Some of these strategies (prevention, reuse, recycling, recovery, disposal) have been central to the European Waste Framework directive established in 2008 (European Commission, 2008, n.d.) and a more expansive framework has been adopted in the recent environmental policies of the EU for a CE (European Commission, 2020a).

The current CE discourse has been initiated and propelled in the last decade by practitioners in business and policy environments, such as the Ellen MacArthur Foundation who popularised the concept and helped convey the business value of a CE  (European Commission, 2020a). The ‘butterfly’ diagram has since become a widespread representation of how a CE system operates, in which a distinction is made between the biological and technical cycles (see Figure 3). The biological loops focus on a regenerative system through renewable resources such as bio-waste, wood, and plant-based textiles. The technical loops focus on finite resources such as plastics and metals, and the diagram clearly illustrates how the inner loops are ‘shorter’, these have a greater potential of retaining the embedded energy and value of the finite resources.

Widely regarded as the ultimate objective of a CE is to decouple economic growth from natural resource depletion and environmental degradation (Liu et al. 2009; Xue et al. 2010). Instrumental in achieving this is the role of service-based and circular business models (CBM), which do not emphasise profit through the immediate selling of products, but rather through the continued utilisation, and the utilisation of the economic value that is retained in products after use in the realisation of new offerings (Linder and Williander, 2017). In product-oriented business models, companies are primarily incentivised to sell as many products as possible and therefore rely on the continuous throughput of resources. In service-oriented business models or product-service systems (PSS), companies are rewarded for prolonging the service life of their products

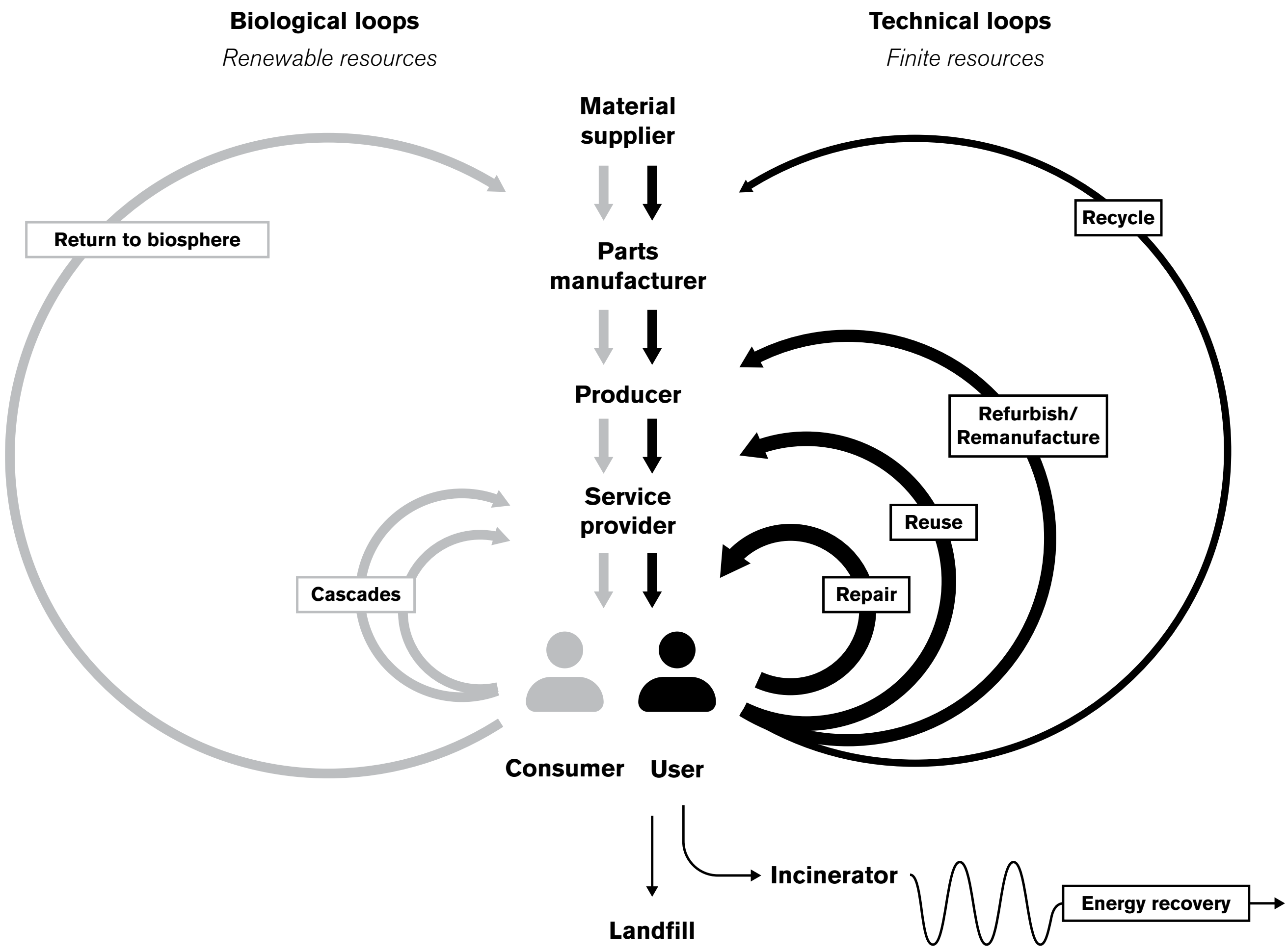


*Figure 3.* CE system diagram, adapted from the Ellen MacArthur Foundation (2013) and Reike, Vermeulen and Witjes (2018).

and ensuring that products are used with as much cost and material efficiency as possible because materials and consumables are cost factors for the company rather than for the consumer (Tukker, 2015). A frequently cited example of such a model is the Philips pay-per-lux program, in which customers pay a fee to have certain areas lighted, and the manufacturer retains ownership of the lights and ensures they always remain functional.

In the EU, scaling up the CE is seen as crucial to achieving climate neutrality by 2050 and implementing the 2030 Sustainable Development Goals (European Commission, 2020a, 2014a). The relationship between the CE and the various sustainable development targets has been examined (Schroeder et al., 2019) and recent literature has shown an increase in connecting and synergising the CE concept with sustainable development (Kirchherr et al., 2023). Nevertheless, some authors argue the conceptual relationship between a CE and sustainable development is not clear (D'Amato et al., 2017; Moreau et al., 2017). The CE has been criticised for the lacking social dimension (Murray et al., 2017) and for neglecting important social factors such as challenging consumption behaviour and the uptake of sufficiency-oriented lifestyles (Schulz et al., 2019). Furthermore, Allwood (2014, 2018) criticised the CE for praising continuous material recycling and avoiding the impacts of new production, while recycling remains energy intensive and almost always leads to the degradation of the material quality (downcycling). Instead, Allwood emphasised the need for material efficiency, facilitating lifetime extension, reusing products and components and reusing materials without energy-intensive processing. Some scholars have also pointed out that decoupling economic growth from resource consumption is a misguided and unrealistic objective, as absolute decoupling from carbon emissions is unlikely at the scale and rate needed to prevent global warming over 1.5°C or 2°C, and the fact that no empirical evidence exists indicating that decoupling from resource use can be achieved on a global scale under the premise of continued economic growth (Hickel and Kallis, 2020).

Recently, the CE literature has also seen an increase in de-growth and post-growth perspectives, arguing that the CE also requires a deep reconsideration of the meaning of doing business and realigning it with social sustainability (Bauwens, 2021). Moreover, consumer and business patterns in a CE should also be steered towards sufficiency (Bocken and Short, 2021; Schulz et al., 2019). Finally, scholars call for complementing and synergising the CE concept with degrowth principles due to the increasing evidence of the link between economic growth and environmental degradation (Hickel and Kallis, 2020; Schröder et al., 2019).

## 2.2 Sustainability in the design professions

Since the Industrial Revolution design has had an important role in the advancement of society and the economy (Press and Cooper, 2016), for instance through the creation of products that made life more convenient, efficient, and promoted human wellbeing. At the same time, the field of design has also been criticised for its role in bolstering the linear economy and consumerism by catering primarily to commercial interests and promoting malpractices such as planned obsolescence (Papanek, 1972). During the first half of the 20th century, the emphasis on product aesthetics or 'styling' emerged in industrial design, which provided society and consumers with the illusion of change when design did not have any real contribution to make (Packard, 1960).

In the early 20th century, products were often designed to enable maintenance and repair, parts were sold and scavenged when products broke down. This, combined with low volumetric flows of products meant that there was little waste. With the progression of planned obsolescence and the widespread adoption of synthetic non-decomposable materials (e.g., plastics), composite materials, and adhesives, the task of disassembling products and reusing components and materials became progressively more challenging. Consequently, this resulted in increasing amounts of waste (Andrews, 2015). Therefore, the development of official landfill sites provided a convenient means for the disposal of waste, which further expanded the cognitive gap between waste and society (Strasser, 2000).

In the second half of the 20th century, sustainability became a more widely discussed topic in the design professions, encouraged by seminal design thinkers such as Buckminster Fuller (1969) and Viktor Papanek (1972). Papanek (1972) criticised industrial design for being a harmful profession by catering primarily to marketeers and commercial interests, and argued that design schools did not teach enough about the ecological, social, economic, and political environment in which design takes place.

Nevertheless, design is often considered crucial in the pursuit of sustainable modes of production and consumption due to decisions made at the design stage. This claim is widely substantiated by the often-repeated statement that up to 80% of the environmental impact of products is determined in the design phase  (European Commission, 2014b; Graedel et al., 1995). Thorpe (2010) nuanced the role of designers by arguing that design is one cog in the wheel of consumerism, and designers are first and foremost commercial actors who need to respond to clients and are educated to 'add value' to business. Moreover, Boehnert (2021) argued how designers are, despite increasing awareness of ecological contexts, currently not able to materialize their priorities and effectively address contemporary environmental and social problems because the system in which design takes place primarily (the design industry) systematically de-prioritizes ecological values.

In response to growing environmental, societal, and global challenges as well as the increasing complexity of sociotechnical systems, the field of design has gradually expanded from object-centric thinking to more system-based design approaches (Gaziulusoy and Brezet, 2015; Manzini and Vezzoli, 2003). The field of design for sustainability (DfS) has over the second half of the 20th century gradually expanded in scope from relatively insular approaches (e.g., a single actor striving to improve the recyclability of a product and optimise product efficiency) to systemic design interventions (Ceschin and Gaziulusoy, 2016) such as sustainable PSS solutions (Manzini and Vezzoli, 2003) which typically involve broad stakeholder networks and a large degree of complexity. In light of these changing circumstances, the roles of designers have become progressively more entangled with the roles of other actors (Joore and Brezet, 2015). Distinct design disciplines emerged such as strategic and service design, that do not primarily engage themselves with the development of tangible and physical solutions, but instead focus on social innovation (Meroni, 2008) and applying design principles to conceive (intangible) solutions for complex societal and organisational challenges.

Through these developments, designers are increasingly challenged to perform strategic roles (Bakker, 1995; Joore and Brezet, 2015; Sumter et al., 2018), establish future visions (Banerjee, 2008), facilitate strategic dialogues between actors (Meroni, 2008) and engage multiple actors and communities in design processes through participatory design and co-design (Bonsiepe, 2006; Gaziulusoy and Ryan, 2017a; Howard, 2004; Luck, 2007; Manzini, 2009; Sanders and Stappers, 2008; Visser et al., 2005). These changing roles of designers are also reflected in the emergence of new design approaches and fields in the last two decades which take systemic approaches to multi-faceted problems in multi-stakeholder contexts, such as service design (Forlizzi and Zimmerman, 2013), design for social innovation (Manzini, 2015), and transition design (Irwin, 2015).

## 2.3 Design for a circular economy

Design for a CE, also commonly referred to as circular design, can be described as a design approach that aims to create artefacts, services, and systems that are restorative and regenerative by nature, so that resources are always kept at their highest utility and value, and waste generation and pollution are minimised. Circular design overlaps to a great extent with sustainable design approaches in terms of general principles and approaches that can be considered under the DfS umbrella (Allen et al., 2023). What sets circular design apart is the underlying principle of a closed-loop economy of resources, thus striving to resolve issues related to waste generation and emphasizing high-value, high-quality cycling of material resources (Sumter et al., 2020). This is in contrast with other sustainable design strategies such as green design (Burral, 1991; Mackenzie, 1997) and eco-design that focus on mitigating environmental challenges, and have been criticised for being 'less bad' rather than good (Braungart et al., 2007; Braungart and McDonough, 2002). In the context of circular product design, Den Hollander et al. (2017) emphasised the need to shift the prevalent assumption that all consumer goods ultimately become waste (e.g., see the European Waste Framework Directive) and proposed an alternative framing where products and components become obsolete, which is a state that can be resisted, postponed, and reversed (den Hollander et al., 2017).

Circular design poses specific challenges for designers, such as anticipating multiple use cycles and entire lifespans (Franconi, 2020; Mestre and Cooper, 2017), deeply understanding materials and their behaviour over time (De los Rios et al., 2017; Lilley et al., 2019), systems thinking (Moreno et al., 2016), and concurrently developing a circular product and business model (Sumter et al., 2018). Moreover, a deeper understanding of the human factors and consumer behaviour associated with a CE is important, to address challenges concerning how the CE affects the way people engage with products and services and their acceptance of new circular value propositions (Daae et al., 2018; Lofthouse and Prendeville, 2018; Poppelaars, 2019; Selvefors et al., 2019).

Den Hollander (2018) pointed out that design briefs are likely to look entirely different in a CE compared to the current linear economy, as the context of a CE requires designers to think about the entire product lifetime, including scenarios of multiple use cycles by multiple users. Another dimension of circular design is that the design of tangible solutions needs to be tailored to and concurrently developed with service-based and circular business models, which ultimately offer the potential to capture value (social, economic, and environmental) of the continuous utilisation and recovery of products, components, and resources (Bocken et al., 2016). As circularity goes beyond business divisions and organisational boundaries and requires intra- and inter-organizational collaboration (Bocken and Konietzko, 2022), designers will also face interpersonal and collaborative challenges and will need to be able to facilitate and engage collaborations across value networks to realise circular value propositions (Sumter et al., 2021). Scholars have also pointed out the importance of systems thinking in design practice and education when addressing the CE (De los Rios et al., 2017; Moreno et al., 2016; Whalen et al., 2018). Systems thinking has been widely studied in the business (Murray et al., 2017) and design literature (Charnley et al., 2011), yet limited research exists indicating whether and how such approaches are applied and adopted in design practice. According to Charnley ( 2011), 'designers have been provided with little guidance as to how these techniques should be implemented efficiently within an operational and substantially complex design process' (p.157).

### 2.3.1 Circular design: A multi-scalar challenge

Artefacts such as consumer products and buildings cannot be designed intrinsically circular, they can only be designed with the potential for circularity. The actual lifespan of a product or building and the extended utilisation of its resources will always depend on socio-economic factors, human behaviour, and the system the artefact is embedded in (e.g., the business model, the structure of the supply chain) (den Hollander, 2018). Thus, circularity (or the qualification of 'circular') within the design process must be understood as the property of a 'system' (Konietzko et al., 2020a), rather than the property of an individual product, building, or service. Such circular systems act on different (or multiple) scales of implementation. The taxonomy proposed by Pomponi (2017) of the micro level (products, components), meso level (buildings and eco-industrial parks), and macro level (cities, built environment) provide a structured and helpful classification for distinguishing the different scales. Systemic approaches to the design of solutions for a CE extend beyond boundaries of scale and discipline. As an example, consider the development of an electronic scooter-sharing system in line with CE principles. A holistic design approach would not only consider the micro scale (the physical design of the scooter) but also the interaction with the built environment (e.g., the physical spaces where maintenance and repair activities take place) and the activities and actors in the value- and supply-chain who are needed for such a system to operate. This is not to say that designers should be responsible for (or are even capable of) the design of such systems with all their intricacies, but rather that design approaches towards the CE benefit from systemic and interdisciplinary approaches that enable 'zooming out' while also considering interactions between different scales of implementation (e.g., micro, meso, macro). As illustrated in Figure 4, the different scales are interrelated and expand in complexity and interdisciplinarity, and the lines that separate these scales become increasingly blurred in the context of circular design.

There are various design frameworks and methods that have been developed to facilitate systemic approaches that integrate and distinguish between different scales, such as the multi-level design model (Joore and Brezet, 2015) and whole-systems design (Blizzard and Klotz, 2012; Charnley et al., 2011; Gaziulusoy and Brezet, 2015). These approaches have also been discussed

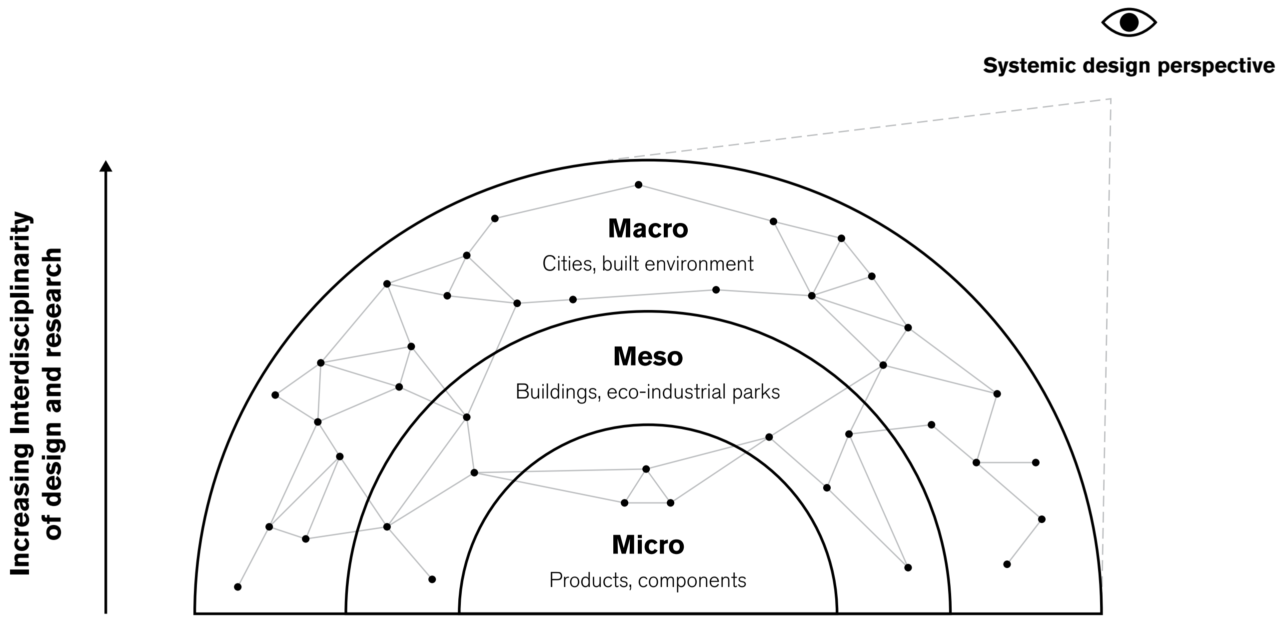


*Figure 4.* The circular economy challenges designers to assume a systemic design perspective and consider the interaction between different scales. The scales are connected and expand in terms of the complexity and interdisciplinarity of the design challenges. The lines separating the scales will become increasingly blurred in the transition to a circular economy.

in the development of sustainable PSS solutions (Ceschin, 2013; Manzini and Vezzoli, 2003; Vezzoli et al., 2015). Nogueira et al. proposed the use of eight capitals as innovation lenses for the CE (natural, financial, manufactured, digital, human, social, cultural, political) to promote systems thinking and capture the full scope of dynamics within a system. The same authors proposed the design-led participatory approach of 'infrastructuring' to address multi-level contexts and find potential collaborations between actors (Nogueira et al., 2020, 2019). The following sections will provide a brief overview of existing research on the CE related to industrial design (primarily the micro scale) and architecture (primarily the meso scale), and supporting guidelines and frameworks that have been developed to support circular design.

### 2.3.2 Circular design within industrial design

The last decade saw an increase in research on product design in the context of a CE, which helped to establish circular product design as a distinct and growing research field. Seminal work by (Bakker et al., 2014) emphasised the importance of balancing product lifetime optimisation with economic viability for the design of circular products, and the need to further research synergies between product life extension strategies and circular business models to deliver solutions with long-term lower environmental impacts while mitigating secondary rebound effects (Kjaer et al., 2019).

Bocken et al. (2016) presented a design framework that proposed the terminology of slowing, closing, and narrowing resource loops and provided an overview of product design and business model strategies that can be utilised in the development of circular solutions. Slowing resource loops can be achieved by designing products in ways so that their lifespan can be extended, for instance through design for repair and maintenance, design for remanufacturing (Boorsma et al., 2020), and design for (functional, emotional and aesthetic) durability (Bakker et al., 2014; van Nes and Cramer, 2006). Closing resource loops refers to designing products so that the components and materials can be eventually reused and recycled, closing the loop between post-use and manufacturing. This can be achieved, for example, by designing products in ways that allow them to be easily disassembled (Go et al., 2015), also referred to as Design for Disassembly (DfD). Finally, narrowing resource loops refers mostly to product optimisation through the more efficient use of resources, for example through avoiding over-design, dematerialisation and more intensive product use (Allwood, 2018; Allwood et al., 2011). While narrowing loops does not contribute directly to circular flows of goods and materials, it is crucial to reduce the rate at which resources are required, which falls within the CE's aim to promote resource efficiency.

Den Hollander (2018) developed the design methodology 'Design for Managing Obsolescence', which posits that circular design should focus on maintaining 'product integrity' over use cycles, and provides a methodology that enables industrial designers to synchronise product designs and business models to maximise the potential for circularity. Den Hollander (2017) suggested the alternative framing of products becoming obsolescent instead of turning into waste, which is a state that be resisted, postponed, and reversed through appropriate design approaches.

Some research efforts have focused on supporting designers in understanding and designing products for multiple lifecycles and developing design frameworks (Franconi, 2020; Mestre and Cooper, 2017). New service solutions and circular business models in which consumers gain access to products and services without owning them have strong implications for the consumption behaviour and processes of people, and their day-to-day interactions with and relationships towards products. Therefore, a substantial body of literature about the design of products has focused on understanding consumer behaviour in a CE and factors that influence the acceptance of circular value propositions (Lofthouse and Prendeville, 2018; Poppelaars et al., 2020; Selvefors et al., 2019; Wastling et al., 2018). Furthermore, other studies have developed concrete design guidelines for circular products ranging from generic guidelines for design and business model strategies (Haffmans et al., 2018; Møller et al., 2023; Shahbazi and Jönbrink, 2020) to specific guidelines to facilitate design for repairability (De Fazio et al., 2021; Pozo Arcos et al., 2021). More exhaustive reviews of existing circular design tools and methods were performed by (Royo et al., 2023; van Dam et al., 2020),

Finally, previous research has discussed the role of digital technology and PSS solutions as an enabler for circular product design. As new smart digital technologies and IoT increasingly turn physical products into feedback-rich systems that can collect data during product usage, they can improve the connection between producers and designers and the lifetime of products (Alcayaga et al., 2019). Moreover, feedback data can become a useful resource for designers to understand how products change, are used, and discarded, improve the design to foster product attachment and trust, and inform design decisions to improve the durability of products (Ingemarsdotter et al., 2020, 2019).

### 2.3.3 Circular design within architecture

The implementation of the CE is frequently discussed in the context of buildings and the construction sector, and the role of architecture and architects herein is vital (European Commission, 2020b). An important strategy for promoting circularity in the built environment is deploying strategies that extend the service life of buildings such as adaptive design and reuse, DfD, and design for repair and remanufacturing (Benachio et al., 2020; Hopkinson et al., 2020; Joensuu et al., 2020; Minunno et al., 2020; Ness and Xing, 2017; Pomponi and Moncaster, 2017). Other approaches include the greater adoption of renewable bio-based materials for building elements, such as mass timber products (Ahn et al., 2022; Campbell, 2018).

The uptake of PSS practices in the built environment has also been discussed, as these systems could help facilitate maintenance activities and the more efficient use of buildings (e.g., through sharing economy principles), which could limit resource consumption and the growth of the building stock (Fargnoli et al., 2019; Joensuu et al., 2020). Digital technologies such as material passports (digital sets of data describing the materials and components in buildings) and digital twins (virtual clones of products and buildings) are also considered as enablers for circular design. These solutions can provide information about the use, recovery, and reuse of materials and components, and inform designers and decision-makers about the technical and spatial reversibility of design artefacts (Debacker et al., 2017). Yet, to date, CE practices in the built environment have focused primarily on waste management and minimization, and the reuse of construction and demolition waste (Joensuu et al., 2020; Munaro et al., 2020).

Cambier, Galle and Temmerman (2020) provided an overview of existing design tools for circular buildings according to different stages of the design process, identifying the following subcategories: design principle tools, material flow analysis tools, life cycle assessment tools, material and product labels, reused material platforms, material passport tools, life cycle cost tools and knowledge sharing platforms. Similar to research on circular product design, the authors point out the potential of PSS solutions as a link between design, business strategies, and the lifecycle management of building assets, which could also affect the role of architects from short-term involvement to long-term involvement with buildings.

### 2.3.4 Supporting circular design

To support the circular design of any artefact, it is apparent that designers need to be supported with assessment methods that identify relevant criteria and metrics for circularity and can help ‘quantify’ the extent to which design proposals support circularity to make better-informed design decisions. In the context of the design of circular building components, (van Stijn et al., 2022a) make the distinction between generative aids that support design synthesis, and evaluative aids that help assess the circularity of a generated design. While material flow analysis (MFA) and LCA are widely considered appropriate methods for the environmental assessment of design options, they have been associated with challenges for designers (particularly in the early design phases) due to the time and level of detail needed to perform one, and the lack of standardisation (Cambier et al., 2020; Kanters, 2020). In regards to generative toolkits for circular design in the built environment, there have been limited academic contributions. Van Stijn & Gruis (2020) analysed

36 existing circular design frameworks, established a comprehensive overview of circular design strategies and developed a design tool that supports an integral approach for circular building components that simultaneously considers the combination of the physical design, circular business models and the value network. The tool is meant for the design of circular building components. Therefore, it is not restricted to the design of buildings and is relevant for both products and the built environment.

Figure 5 shows a combined visual overview of the circularity strategies from the R9 model by Potting et al. (2017) and different technical design strategies identified by Van Stijn and Gruis, which are classified according to the categories of narrowing, slowing, and closing resource loops by (Bocken et al., 2016). The list of strategies is not meant to be exhaustive; the figure aims to illustrate connections between the three fundamental strategies that contribute to a CE, the resource value retention options, and the technical design strategies that can be deployed by designers. Theoretically, it is beneficial to move upwards in the list as these strategies are more effective at retaining the value of finite resources and cause less environmental pressure. Yet, as pointed out by (Bocken et al., 2016), narrowing loops alone will not lead to a CE as it primarily affects the demand for resources and not the speed of resource flows (e.g., selling vast quantities of a more efficient product will result in little overall savings).

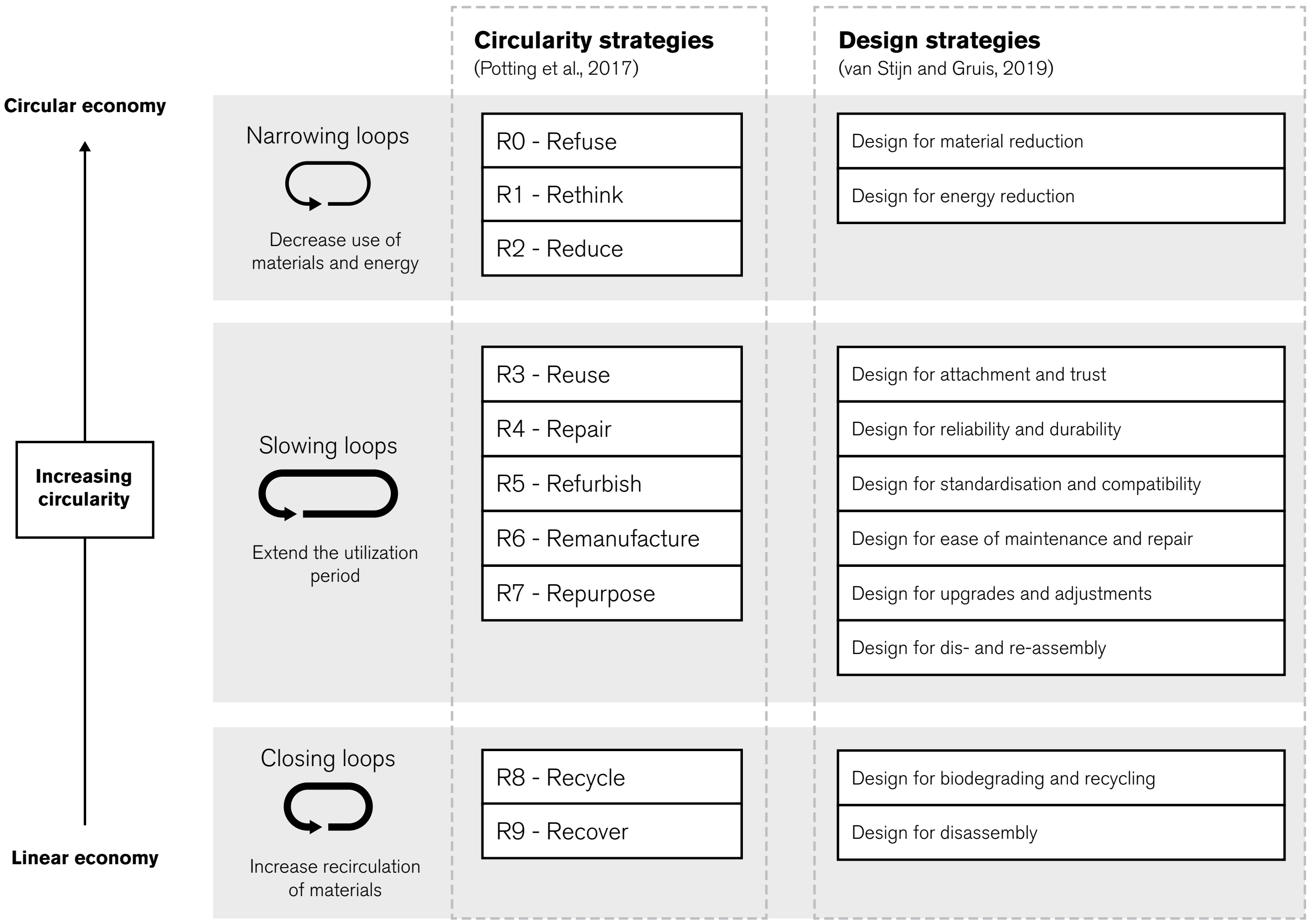


*Figure 5.* An overview of the generic circular strategies for value chains and design strategies to support the different resource cycles of narrowing, slowing and closing loops.

### 2.3.5 Circular design: an emerging practice

Based on the existing literature, it is apparent that in both the context of products and the built environment, extensive research has been conducted to develop appropriate guidelines, expertise, and methods to support circular design efforts. In many ways, research on circular products and buildings reports similar design strategies that facilitate lifetime extension such as design for repair and maintenance, DfD is an important strategy for closing and extending resource loops. At both levels, PSS solutions and the ongoing development concerning digital technologies appear to be enablers for circular design as these can eventually support designers in better understanding how products and buildings are used and change over time, and optimise them towards circularity. To date, there has been limited research examining design for a CE from the perspective of both products (micro scale) and buildings (meso scale), and exploring the interplay between these scales.

In practice, the term circular design has gained much attention in the last decade in policy and business environments. Early in the contemporary CE discourse, the Ellen MacArthur Foundation propagated the 'restorative role of design' (Ellen MacArthur Foundation, 2013) and collaborated with design and innovation company IDEO to develop the Circular Design Guide. The guide provided designers with a framework to operationalise circular design and included tools, case studies, and best practices (Ellen MacArthur Foundation and IDEO, 2017). Moreover, the Ellen MacArthur Foundation collaborated with ARUP to develop the Circular Buildings Toolkit, which is a comprehensive framework for designing circular buildings based on relevant international practices and policies (Ellen MacArthur Foundation and ARUP, 2022). Subsequently, a plethora of circular design guides, methods, and tools have been developed by various actors (NGOs, trade unions, consultancies, manufacturers) and for different design disciplines (product design, fashion, architecture, interior design, service design) which illustrate the CE concept and often convey the basic principles of circular design.

Cambier et al. (2020) pointed out the oversupply of tools illustrating the basic principles of circular building and the mismatch between ongoing developments and the actual needs of practitioners. In the context of eco-design, (Ahmad et al., 2018) noted that many sustainable product design tools lack practical utility and that the uptake of such design tools needs to be supported by coordinated and responsible efforts amongst practitioners, governments, societies, and researchers. In the context of circular design, there are indications that such coordinated efforts are ongoing in Europe; there are several governmentally supported initiatives to gather and distribute knowledge about circular design to designers and manufacturers (e.g., Circo in the Netherlands, The British Design Council in the UK, Stiftelse Svensk Industridesign in Sweden, and Danish Design Center in Denmark).

A wide variety of supporting design frameworks, tools and methods have been made available to designers to operationalise the CE concept in their design efforts, of which most appear to be generative aids and guidelines (i.e., lists) illustrating the basic principles and strategies for circular design. Yet, there is still little evidence of how design practitioners engage with circular design in practice, and whether these frameworks and the widely available design knowledge, tools, and methods are sufficiently supporting designers in tackling the challenges associated with designing for a CE.

### 2.3.6 The role of designers in a circular economy

The transition to a CE likely has implications for the role of designers in practice, both in the context of architecture and industrial design. As circular product design strategies and business model strategies will need to go hand in hand (Bocken et al., 2016), the role of industrial designers will shift from a predominantly operational one to a more strategic business one, requiring further collaboration between designers and other disciplines such as marketing and further knowledge of business sciences (den Hollander, 2018). De los Rios et al. (2017) indicated that product designers have to develop deep material knowledge, proficiency in service design, and a richer understanding of social behaviour to design for a CE. The same author suggests that the specific challenges of a CE are best addressed through specialist design 'personas', such as the PSS designer or retrofitting designer. Sumter et al. (2021) defined a comprehensive set of skills and competencies for designers to become more proficient at designing for a CE, these skills include systems thinking, anticipating future use cycles of products, assessing environmental impacts, stakeholder collaboration, and business and material knowledge.

It has been pointed out that the design of circular business models probably falls outside the domain and responsibilities of designers and architects (Bakker et al., 2014; Cambier, 2022), yet the design choices they make will affect the business models and vice versa. Therefore, designers must have an understanding of how (circular) business models function to find synergies between design interventions and circular business propositions, which will require dedicated competencies (Sumter et al., 2021)

Galle et al. (2015) highlighted that the role of architectural designers needs to change from short-term involvements to long-term engagements, to encourage lifecycle thinking and ensure that the long-term management and maintenance of buildings is thought through. Based upon a set of architectural case studies, (Kozminska, 2020, 2019) noted that the circular design process differs substantially from the standard design process, especially when the reuse of obsolescent building materials and components in projects is a core strategy. Accordingly, the introductory phase is extended due to the search and quality assurance of the reused materials, and the necessary additional testing and collaboration with experts. Moreover, more flexibility needs to be incorporated into projects due to the uncertainties in the cost plan, schedule, and suitability and availability of materials. Overall, the design process requires extensive interdisciplinary collaboration and should encompass the lifecycle of materials to define future methods of maintenance, disassembly, and the reuse of materials and components. Kanters (2020) noted the pivotal role of architects in the transition to a CE, by linking different actors (e.g., client, contractor, other consultants, and engineers) and providing innovative solutions, yet would require leadership capabilities and deeper material knowledge to perform this role effectively. Cambier (2022) also noted this necessity for central figures who facilitate strategic dialogues and collaboration in the development process and value chain of construction and pointed out that it remains uncertain whether architects are willing and capable of doing this, or if other actors are better suited such as the property developers (Leising et al., 2018). As pointed out by Charef and Lu (2021), it is apparent that the uptake of circular design strategies in the construction industry will be difficult without disruption of conventional design practice and a radical shift in the way that projects are structured.

In the context of retail design, Münster et al (2022) found that the designers' influence to incorporate circular design is ultimately dependent on market economics and willing clients. Furthermore, they argue that there is a need for a systemic and collaborative approach between actors in retail design processes, and the central role design can play needs to be articulated, practised, and broadcasted. Dan and Østergaard (2021) examined how fashion designers can aid the transition to a CE and suggested that they can take three central roles (prevent, facilitate, and advise), yet these would require systemic and organisational changes (related to designer knowledge, dynamic capabilities, better design management, and balanced power structures).

Overall, the examined literature indicates that despite promising intentions and developments within design practice, the conventional modes of design practice (particularly in consultancy settings) and the prevalent systemic challenges inhibit design practitioners from effectively incorporating circular design and aligning their efforts to the CE. This finding is not unique to the context of a CE; in recent decades various scholars noted that it has proven difficult for design practice to effectively address social and ecological problems and challenge the underlying premise that the role of the designer is to work within the system of consumer culture and provide services to clients (Margolin, 1998; Thorpe, 2010). The transition from a linear to a circular system however appears to represent some shifts in professional design practice, for example concerning the role of designers and the involvement of design organisations in the value chain of product manufacturing and construction. For example, some architectural agencies facilitate and specialise in the storage, sale, and reuse of salvaged materials and components to support circularity (RotorDC, n.d.; Superuse, n.d.). Yet, the wider practical implications of the CE for the practice of architects and industrial designers remain under-explored, and there is a lack of wider understanding of the ongoing efforts and challenges concerning circular design.

## 2.4 Circular business models and innovation for a circular economy

A crucial element in the operationalisation of the CE is the uptake of circular business models (CBM). Business models can be described as the way firms convert resources and capabilities into economic value (Teece, 2010), and they can be defined according to three main elements: value proposition (the product or service offering), value creation and delivery (how value is created and delivered to customers), and value capture (how revenue is generated). In a CBM, the key challenge is how to capture economic value of delivering the social and environmental benefits of resource circularity (Bocken et al., 2014). In a linear business model, each step in the value chain adds value to a given product and the product is sold at its highest value, after which the product value goes downhill, and the manufacturer no longer captures any value of the product. This in turn creates an incentive for manufacturers to shorten product lifespans (Bakker et al., 2014) to continuously sell new products. The shift from a linear business model to a CBM requires radical changes to the value creation logic of a company, as profit is not generated through the immediate selling of products but through their continued utilisation, and the utilisation of the economic value that is retained in products during and after their use into new offerings (Linder and Williander, 2017). This contrast in value creation logic between a linear and circular business model can be illustrated with the analogy of a value hill (Achterberg et al., 2016), as shown in Figure 6.

To enable the shift from linear to circular business models, companies will have to pursue circular business model innovation (CBMI), which concerns the conceptualisation and implementation of CBMs, the process of creating a circular start-up, transforming a business model into a circular one, and diversifying into and acquiring CBMs (Geissdoerfer et al., 2020). While extensive research has been conducted on the theoretical development and conceptualisation of circular business models, there have been fewer research efforts addressing how to move new business models from concept to implementation and generate the necessary practical impact, also referred to as the 'design-implementation gap' (Baldassarre et al., 2020a). To bridge the gap between ideas and implementation, scholars have recently investigated how to link sustainable design theory and design thinking frameworks with the process of CBMI (Baldassarre et al., 2020a; Geissdoerfer et al., 2016; Guldmann et al., 2019; Santa-Maria et al., 2022a). Deploying these design-driven approaches can help facilitate iterative processes that emphasise co-creation, prototyping, and real-life experimentation, ultimately supporting practical implementation.

A challenge for companies operating at the micro-level (products, components) is that their product, business model, and supply chain need to be concurrently (re)aligned towards circularity. This requires companies to think outside their organisational boundaries and adopt a circular ecosystem perspective (Konietzko et al., 2020a). While CBMI emphasises the business perspective, the framing of circular-oriented innovation (COI) is helpful as it encapsulates the combination of product design, business model innovation, and value network configurations to investigate the operationalisation of CE strategies (Blomsma et al., 2019a; Brown et al., 2021b). Value network configuration can be described as the way actors in the value chain (from upstream suppliers, manufacturers, downstream distributors, to consumers) interact and collaborate. These value networks need to be structured in a way that enables actors to benefit from the extended utilisation and circulation of products and resources. Through the process of COI, companies can maximise value creation (in terms of economic, societal, and environmental value) by slowing and closing resource loops (Bocken et al., 2016; Geissdoerfer et al., 2020). To date, there is a lack of case-based evidence of how companies go through COI, particularly from a design process perspective,

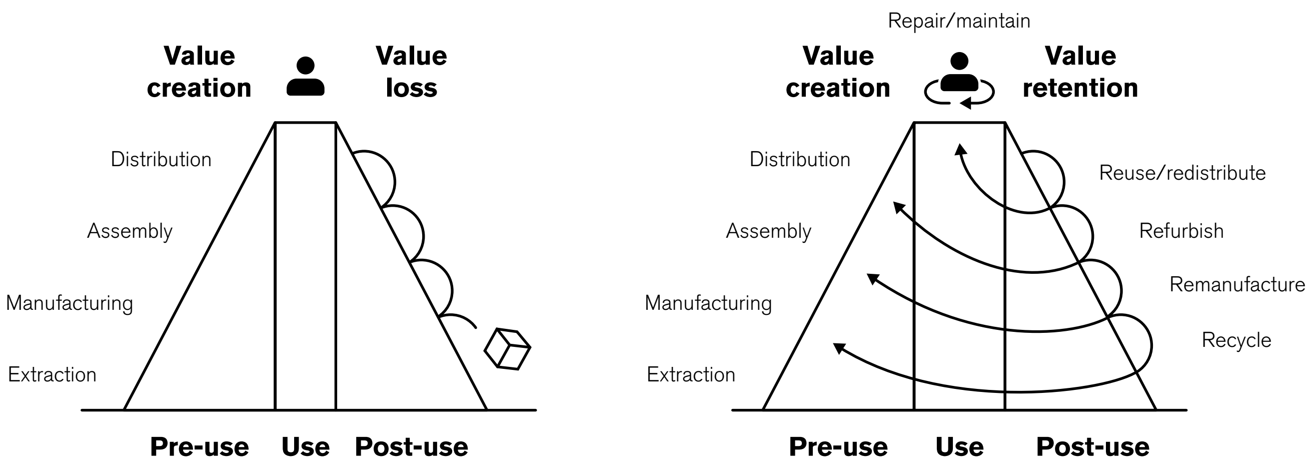


*Figure 6.* The value creation logic of a linear business model (left) and a circular business model (right). Adapted from Achterberg et al. (2017).

and how design-driven approaches that emphasise co-creation, experimentation, and prototyping contribute to the process of COI.

## 2.5 The role of collaboration and co-creation in circular-oriented innovation

Organisations will be increasingly challenged to collaborate across entire supply chains to enable the continuous utilisation and circulation of resources, from the upstream suppliers (e.g., for the recycling of materials) to downstream distributors and consumers (e.g., for the reverse logistics of products and components). Scholars widely agree that supply chain collaboration is a crucial factor to realise a CE (Blomsma et al., 2019b; Brown et al., 2021b; Geissdoerfer et al., 2018; Ghisellini et al., 2016; Konietzko et al., 2020a; Leising et al., 2018; Santa-Maria et al., 2022b). In the EU, the lack of willingness to collaborate within value chains forms one of the major barriers to a CE (Kirchherr et al., 2018). In the context of the built environment, the lack of a collaborative and holistic approach within the supply chain and the 'silo' approach towards design, construction, facility management and EoL activities are considered to be the key challenges (Adams et al., 2017; Hart et al., 2019). The composition of partnerships, the importance of relationships, and the formation of networks and new alliances represent challenges that go beyond current CE practices that primarily focus on material flows (Nogueira et al., 2019).

Aminoff et al. (2016) noted that the transition to a CE will not succeed if actors primarily focus on advancing their own individual interests, instead, they will need to establish new ways of working, new business partners, new roles of existing partners, and new collaborations between stakeholders. This represents the major challenge of collaboration in the context of CE as pointed out by Brown et al. (2020); how to shift the traditional mindset of maximising individual benefits towards exploring the potential of shared value for multiple actors from a whole-system perspective. Brown et al. (2020;2021) provided insights about collaboration in the process of COI and highlighted four important challenges related to COI: aligning actors on a shared circular proposition, the external facilitation of this process (in which scientific bodies can have a meaningful role), developing CE-oriented governance and decision-making, and enabling a suitable context for iterative experimentation. Based on a case study of a collaborative project focusing on CE in the Danish construction sector, Köhler et al. (2022) investigated the role of open innovation and dynamic capabilities and highlighted the dilemma of firms being reluctant to share knowledge and ideas openly due to the fear of losing competitive advantage. The same authors emphasized the need to create a setting in which firms are encouraged to share ideas without losing competitive advantage and recommended a mix of formal and informal agreements to find the best balance between knowledge protection and sharing.

Previous research discussed the importance of the (re)configuration of value chains and value chain collaboration in the process of designing for a CE, and the implications of this for the role of designers. Sumter et al. (2020, 2021) emphasised the need for interpersonal and collaborative competencies among industrial designers and defined 'Circular Economy Collaboration' as the capability to 'facilitate and engage collaborations across value networks to create circular product-service systems and stimulate the transition toward a circular economy'.

COI processes will typically involve a multitude of stakeholders with diverse agendas, interests, and perspectives (which are potentially aligned or conflicting). Here, participatory design approaches (co-creation, co-design) can be important as they enable creative collaboration in multi-stakeholder settings and provide a democratic function in systemic transformations where neither agency nor power is evenly distributed amongst actors (Gaziulusoy and Ryan, 2017b).

Participatory design approaches such as co-creation and co-design are relevant in the context of the CE as they promote the collaboration between and inclusiveness and representation of various actors and perspectives in the design process including the users, clients, experts, value- and supply-chain actors, and other stakeholders. The practice of collective creativity and user participation in the product development process (i.e., participatory design) has its roots in Scandinavia and dates back to the 1970s (Sanders and Stappers, 2008). The fundamental idea is that design should take place with people or by people instead of for people, and the Nordics have a rich history of collaborative design approaches between designers and non-designers often motivated by democratic or political aims (Göransdotter, 2022). While co-creation can refer to any act of collective creativity, co-design is rooted in design practice and specifically involves collective creativity between designers and people who are not trained in design, as a part of the design process (Sanders and Stappers, 2008). The term value co-creation also emerged in the business and management literature, which more specifically refers to collaborative value creation within firms and within networks of actors  (Jaakkola and Hakanen, 2013).

Through time, participatory design developed from being concerned with involving users in evaluative research (i.e., testing existing products or prototypes) to taking part in generative research and techniques that inform designers in the early design phases (Visser et al., 2005). In the context of the CE, participatory design is, on one hand, crucial for gaining a better understanding of the way people might engage, interact and accept circular and service-based solutions that are often 'accessed' rather than 'owned'(Poppelaars et al., 2018). On the other hand, participatory design approaches are relevant to enable holistic approaches towards the development of circular value networks in which wider sets of value chain actors are involved and need to collaborate to enable the circulation and cascading of resources (Blomsma et al., 2019b).

Pedersen and Clausen (2019) emphasised the role of designers as 'orchestrators' who utilise co-design methods and can stage negotiations between actors and (re)align their values through designing prototypes as 'knowledge objects'. In this case, the designer acts as the connector and facilitator (Manzini, 2009) who stages connections between stakeholders and creates the setting for circular innovation. Luck (2007) investigated and compared experienced expert architects and architectural graduates and found that the effectiveness of participatory design to some degree is reliant on the expertise of the facilitator, and the skills to facilitate participatory design workshops are learned over time and through experience in practice. Therefore, it is important that students in design education gain knowledge and experience of how participatory and co-design methods can be utilised in projects to drive the adoption of circular and sustainable solutions (Faludi et al., 2023).

Ezio Manzini (2017) discussed how the role of the design expert and facilitator in co-design processes is often reduced to 'post-it design' (i.e., taking a step back and asking other actors to stick their opinions and wishes on a wall that are then collected and synthesised following a rather formalised process). Instead, Manzini emphasised that design expert facilitators should be simultaneously critical, creative, and dialogic and feed conversations with visions and ideas, listen to feedback from the actors and the environment and then introduce more mature proposals into the conversation.

Various prescriptive frameworks and methods have been developed to stimulate CE collaboration and facilitate co-creation in COI. Some research efforts have focused on the theoretical perspective of collaboration in the process of developing circular value propositions and developed process models (Blomsma et al., 2019b; Bocken et al., 2018; Brown et al., 2021b; Leising et al., 2018). Other works include generative aids to stimulate collaboration in the development of circular ecosystems (Konietzko et al., 2020b) and frameworks that incorporate elements of design thinking and provide practical guidance for collaboration in COI including different phases, activities, and proposed timelines (Blomsma et al., 2020; Brown et al., 2021a; Guldmann et al., 2019; Santa-Maria et al., 2022a).

Overall, it is apparent that the success of design efforts in the context of the CE will rely to a substantial degree on the collaboration between actors across the value chain (and their willingness to collaborate). Hence, considering the role of value chain collaboration and the formation of circular value networks as a part of the design process can be of importance. Based on the investigated literature, it is apparent that the potential of participatory design and co-design methods have not yet been extensively investigated in the context of COI. Blomsma et al. (2019) noted that stakeholder management is a common theme in CE research, but little research has focused on investigating methods for the co-design of CE value chains in terms of how to select strategic partners, when to engage them and in what capacity. Apparently, co-creation and co-design approaches can contribute to COI, but limited empirical studies on COI exist that aim to better understand the role of co-creation and co-design throughout different stages of the COI process. Moreover, there has been limited research on how existing frameworks and approaches towards stakeholder co-creation can be effectively integrated and adapted to the design process to support designers in the development of solutions for a CE.

## 2.6 The role of prototyping in circular-oriented innovation

As described in the previous chapter, prototyping is an important strategy in the context of COI as it can facilitate negotiations and alignment between actors and help bridge the gap between the conceptualisation and implementation of CBMs. By conducting pilots with prototypes, organisations are encouraged to simultaneously consider the desirability (what people want), feasibility (what is technically achievable), viability (what is economically achievable), and sustainability (the potential social and environmental benefits) of a circular value proposition (Baldassarre et al., 2020b). Prototyping involves the development of tangible and intangible artefacts to explore, evaluate, and demonstrate the usability, function, and form of products (Houde and Hill, 1997). Pilots go a step further and can be defined as semi-controlled launches and tests of product and business concepts with target markets within a small-scale and easy to analyse setting (Geissdoerfer et al., 2022).

Prototyping can be considered as a common strategy in the toolbox of designers and forms an integral component of product development processes (Roozenburg and Eekels, 1995) as well as in architectural practice (Sherwood, 1978). The link between the act of prototyping and processes of collaboration and co-creation should not be underestimated; prototyping can be a strategy to foster collaboration between designers and (external) stakeholders. Within design processes featuring many diverse stakeholders, prototypes can function as boundary objects that can help align knowledge and perspectives between the stakeholders. Different types of prototypes can also trigger different modes of collaboration. For instance, a 'proof of concept' can trigger provocation and initial engagement of stakeholders, while a more detailed 'proof of product' can be used to test experiences (Kleinsmann and Ten Bhömer, 2020). In multi-stakeholder settings, it is also important to become aware of the biases that prototypes may generate and how prototypes are leveraged in social situations and the communication between stakeholders (Lauff et al., 2020), as this could hinder – or contribute to the development process.

Pilots are important in the context of the CE because the actual lifespan and environmental performance of a product will always depend on socio-economic factors (e.g., the business model of the product, consumer acceptance and behaviour) as well as the configuration and operation of the value network. By developing prototypes and utilising them to execute small-scale pilots with the intended stakeholders, a holistic assessment can take place of a particular circular product design strategy alongside a circular business model concept and a particular supply chain configuration (i.e., how stakeholders are supposed to collaborate to enable the circulation and extended utilization of resources). As an example, applying a modular design approach to a headphone and assessing prototypes with users might provide evidence of whether the repair of components is feasible and intuitive, but it will not ensure that the headphones are used for longer and that fewer headphones will be disposed of. Yet, running a pilot with such a prototype alongside a particular business model concept (a subscription including free repairs and replacements) and a particular supply chain configuration (distributors that deliver replacement parts through the post) might provide evidence of whether such a value proposition is viable and can enable the extended utilisation and recirculation of resources and materials.

To date, few empirical studies have investigated the role of prototyping and pilots in relation to COI. In the context of urban development, Nogueira et al. (2020) notes that prototyping is used as knowledge brokering to explore "alternative futures co-defined by agents who do not interact with one another normally" and "explore previously unarticulated (and often hidden) connections and challenges related to CE practices" (p.5). In the context of co-design for a CE, Pedersen et al. (2019) highlighted the role of mock-ups and prototypes as knowledge objects, to stage negotiations between actors and (re)align their values. Furthermore, Guldmann et al. (2019) proposed a CBMI framework based on design thinking and appointed a prototyping and testing phase to examine circular business model ideas and undertake pilot experiments. While these studies have supported the framing and understanding of prototyping in the context of the CE, there are still few empirical studies based on real-life cases that examine how prototyping as a collaborative process, and prototypes as knowledge objects, support the process of COI.

# 3. Methodology

## 3.1 Research approach and worldview

Due to the background of the researcher, as well as the context in which this thesis is situated, this thesis adopts the perspective that a transition to a CE is desirable for humanity to promote sustainable development and move towards more sustainable modes of production and consumption. The researchers' experience of working with design in practical settings and addressing sustainability issues in real-world contexts influenced the research orientation and contributed to a pragmatist perspective. Both the personal background of the researcher and the context in which the research was situated (the circular kitchen project; the starting point for this research) have led to the adoption of a pragmatic-oriented approach towards the research where (design) processes and encountered contexts demanded different forms of inquiry depending on what was deemed most suitable at the time.

Pragmatist researchers look at what and how to research based on intended consequences, drawing liberally from quantitative and qualitative assumptions, and select methods, techniques, and procedures of research accordingly (Creswell, 2009). This differs from (post)positivist perspectives which advocate a commitment to one system of philosophy or reality, based upon the notion that an objective reality exists in the world which can be measured. While the author shares the notion that realities are multiple and socially constructed depending on the context and locale of individuals, the author also sees fundamental limitations in the interpretivist notion that research (by definition) is context-specific as it makes the generalizability of the research practically impossible. Essentially, interpretivism neglects the importance of causal relationships and generalizability, while positivism overlooks the complexity and contextual factors in social research (Patton, 2002a). Pragmatism advocates the use of mixed methods as a pragmatic way to understand human behaviour (Kivunja and Kuyini, 2017), and is therefore better suited to address the complexity of social issues and contribute to meaningful social change.

The conditions of much of the research that was carried out as a part of this thesis were transdisciplinary and solution-oriented. Transdisciplinary research is highly unpredictable and despite defined and mutually agreed research goals and ambitions between involved participants, the process and outcomes are largely dependent on factors such as stakeholder engagement and commitment (Polk, 2015) which are uncertain and difficult to predict beforehand. This asked for a research approach which emphasized flexibility, practicality, problem-solving, and the integration of diverse perspectives.

The recent resurgence of the CE concept in the form of the contemporary CE approach has been primarily led by practitioners in business and policy environments (e.g., see Ellen MacArthur Foundation 2013; European Commission 2014b, 2015). From a scholarly perspective, conceptual discussions on the CE are still nascent (Korhonen et al., 2018) and a plethora of interpretations and definitions of the CE concept exist (Kirchherr et al., 2017). The same phenomenon can be observed with the theme of circular design which has surfaced in the last decade; circular design is presented as a promising avenue or 'vehicle' towards more sustainable design practices, yet the concept is ill-defined and the practical implications of designing for a CE are not yet well understood. Therefore, it is not unlikely that different practitioners (including designers) adopt their own interpretations and definitions within the context of their practice, which are not necessarily aligned with the underlying goals of a CE and sustainable development. The transition to a CE, and the role of design within this transition, represents a 'wicked problem' (Rittel and Webber, 1973). It encompasses more than technical challenges for which solutions can be derived through scientific or engineering methods of inquiry, it features complex societal challenges which require a systemic shift in the way resources are perceived and utilised. A wicked problem does not have a clear solution because it is part of the social fabric in which it sits (Brown, 2008), therefore, solutions to wicked problems generate waves of consequences, yielding potentially undesirable repercussions and generating new problems that require new solutions.

The thesis incorporates the use of both qualitative and quantitative methods and adopts a mixed methods approach. This allows for developing a detailed understanding of the meaning of a concept for individuals while allowing for the triangulation of data sources (Creswell, 2009), and generalising findings to a population while developing knowledge that is meaningful and impactful in a wider sense. The mixed methods approach took place primarily in a sequential fashion, where qualitative inquiries (e.g., interviews) allowed for inductive explorations, and were followed up by quantitative surveys with larger samples to allow for generalisation and more robust findings.

A Participatory Action Research (PAR) approach was adopted for the research carried out directly connected to the CIK project, which emphasizes problem-solving, contextual understanding, stakeholder engagement, and reflective learning, therefore fitting well into a pragmatic paradigm. In PAR, participants with different power, status, influence, and facility come together to work on a thematic concern (McTaggart, 1991). The participants seek pragmatic and meaningful solutions to social problems in organisations, communities, and societies, based upon a cyclical process of planning, acting, observing, and evaluating (Lewin, 1946).

Rather than seeing research and design as two separate activities, the author sees them as complementary activities where 'research can inform design in many ways and at many times in the design process; and the design process and the eventually designed artefact can yield an abundance of questions that lend themselves to many forms of inquiry' (Groat and Wang, 2002, p. 25). Designers solve problems through synthesis and rely on 'solution-focused' strategies to intervene in reality (Cross, 1982). Overall, this thesis can be considered within the frame of design research, which can be defined as 'the study of how designers work and think, the establishment of appropriate structures for the design process, the development and application of new design methods, techniques and procedures, and the reflection on the nature and extent of design knowledge and its application to design problems' (Cross, 1984).

This thesis incorporated both Research for Design (relating to research that aims to advance the practice of design; Frayling 1993) and Research through Design (RtD) to explore potential

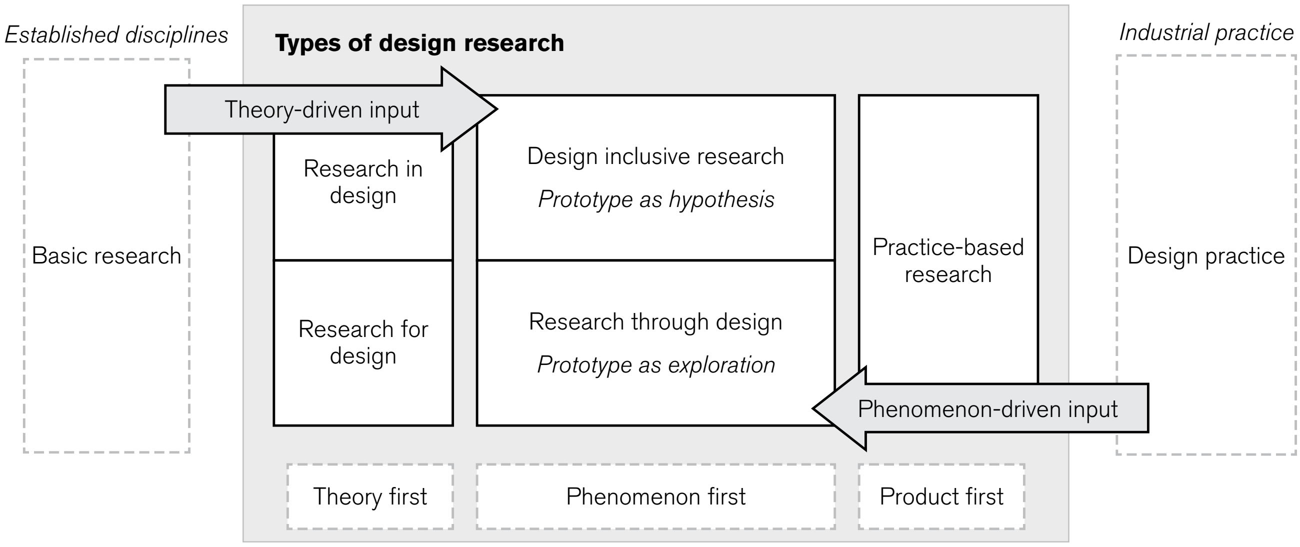


*Figure 7.* Types of design research (adapted from Stappers, Visser & Keller 2014 and Horvath 2007).

futures and develop actionable knowledge to advance circular design in practice. In RtD, the design action itself is essential to knowledge generation and is carried out by the designer-researcher (Stappers et al., 2014). As can be seen in Figure 7, the goal of the designed artefact in this case is to gain knowledge by exploring a phenomenon (phenomenon-driven input), even if the designed artefact might result in a product as a side-effect (Horvath, 2007). This was the case for study 3, where a process (circular design) was explored through the use of a prototype (the card-based design tool), where knowledge was gained about the process of circular design, yet the development of the artefact and the artefact itself also became a contribution and led to further inquiries. In the next section, the aims of the specific studies and the utilised methods are further elaborated.

## 3.2 Research design

The research intends to contribute to bridging the gap between circular design in theory and practice. By gathering empirical data from design practice, this work aspires to create a better understanding of how design practitioners currently (and could further) contribute to a CE transition, and what is needed to advance circular design capacity in practice. The thesis aims to provide insights that are relevant for both design practitioners and (design) researchers. To satisfy the aims mentioned in section 1.1, the thesis builds on three studies (numbered 1-3) that are outlined in Figure 9. Considering the limited empirical research that has been conducted related to design for a CE to date, the research adopted an approach that can be divided roughly into two parts: the first part (study 1) gathers insights by exploring how design for a CE is currently applied in practice while the second part (study 2 and 3) investigate how efforts in practice can be further supported. The following section provides a summarised description of the methods used in each of the studies A-C.

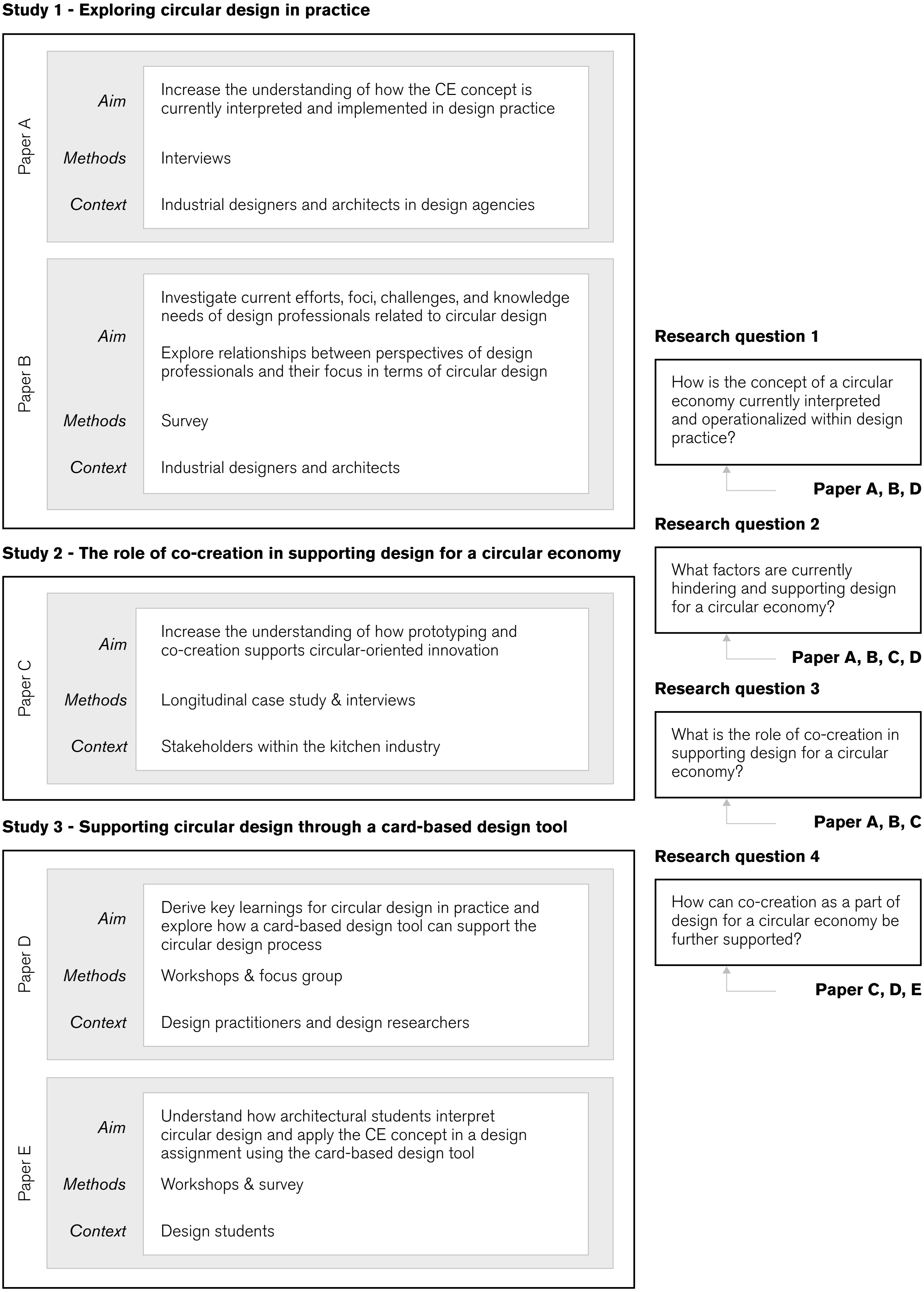


*Figure 8.* Overview of the three studies and corresponding papers included in this thesis and their relation to the research questions.

### 3.2.1 Study 1: Exploring circular design in practice

Study 1 aimed to enhance the understanding of how design professionals within the discipline of architecture and industrial design currently interpret and implement the concept of a CE in design practice. Additionally, the study aimed to gain a better understanding of the challenges encountered in practice and the knowledge needs of design professionals related to circular design. Study 1 encapsulates two research papers (A and B). Paper A followed an explorative and inductive approach by interviewing design professionals with CE experience, while paper B corroborated the findings of study A through a survey study which focused on how circular design is deployed on a wider scale.

INTERVIEWS WITH INDUSTRIAL DESIGNERS AND ARCHITECTS (PAPER A)

Insights were gathered from design professionals who participated in design projects or worked for agencies with circularity as an articulated focus or theme. The study utilised semi-structured interviews to (1) allow for a broad exploration of topics while maintaining an openness towards more detailed responses and (2) enable the participants' terminology and values to be expressed and capture their individual perceptions and experiences (Patton, 2002b).

Between January 2020 and July 2020, a total of 12 interviews were conducted, which lasted between 60 and 96 minutes. An interview guide was developed that covered general, project- and design-specific questions (see appended paper A). The general questions addressed how the participants currently interpret and work with the CE in design practice, the project questions inquired about experiences and reflections from CE-focused projects, and the design questions addressed how the CE has affected their process, role, and capabilities. The interview data was complemented with written notes and case-specific information gathered from the companies.

The aim was to select participants within the disciplines of architecture and industrial design who work in consultancy settings to acquire rich and representative data drawing on experiences from multiple cases. Participants were selected based on the following criteria: (1) the participant has been involved in design projects with an explicit focus on circularity, and/or (2) the participant

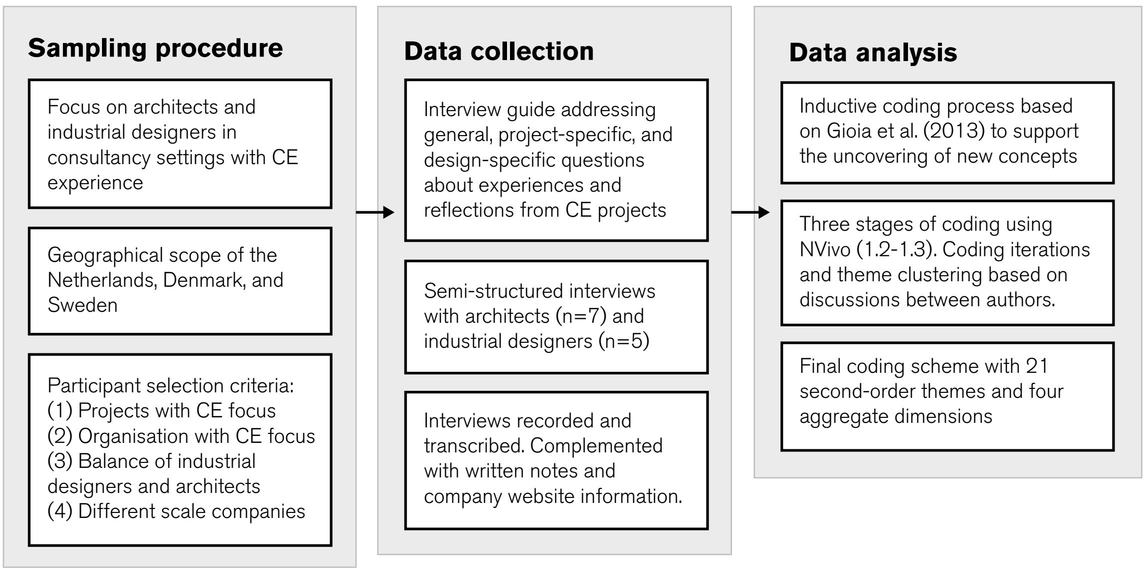


*Figure 9.* Overview of the research approach for paper A.

is part of an organisation with a particular focus on designing for a CE, (3) a balance of industrial designers and architects is represented and (4) companies of different scale are included. The scope of the study and participants was limited to the EU, where design plays a central role in CE policies (e.g., see European Commission 2020a). For a more detailed description of the participants, see appended paper A.

To support the explorative aim of the study, the study followed an overall inductive approach to not be constrained by predetermined categories of analysis (Patton, 2002b). To enhance the qualitative rigour of the study, the data analysis followed the methodology proposed by Gioia, Corley, and Hamilton (2013) and deployed a three-tiered iterative coding process. The initial analysis identified first-order themes based on emerging informant-centric themes, the second step searched for relationships between first-order codes to establish second-order themes, which were finally assembled into four aggregate dimensions (for the detailed coding scheme, see appended paper A).

### SURVEY WITH INDUSTRIAL DESIGNERS AND ARCHITECTS (PAPER B)

The survey focused on architects and industrial designers in the Netherlands and Sweden. The primary aim of the survey was to investigate the current foci, efforts, challenges, and knowledge needs of design professionals related to circular design. In addition, a secondary aim of the survey was to explore what relationships exist between the perspectives and characteristics of the design professionals and their focus in terms of circular design. The Netherlands and Sweden were considered suitable candidates for further inquiry, considering the purpose of consolidating paper A, and the fact that both the Netherlands and Sweden have an active agenda promoting CE and circular design.

A purposive sampling method was followed (Groat and Wang, 2002) targeting professional unions for designers and architects to ensure a random sample of design professionals from different design disciplines, organisations, and experience levels. The survey was distributed via trade unions for architects and industrial designers in the Netherlands and Sweden, via LinkedIn, and direct emails to addresses gathered from the trade unions and the author's professional network. A total of 114 valid responses were gathered.

The survey questions were developed to assess the current foci and practices of the architects and industrial designers regarding circular design, and addressed experienced challenges, changes and efforts in organisations, and necessary knowledge related to circular design. To gain an understanding of the current foci of participants regarding circular design, participants were asked to indicate what design strategies they incorporated in projects focusing on CE. Participants who did not have experience with CE projects were shown the same list of strategies but were asked instead which strategies they have generally incorporated in design projects. The list of strategies was adapted from a comprehensive framework based on relevant international practices and policies (Ellen MacArthur Foundation and ARUP, 2022) and featured a hierarchical grouping (based on the extent they retain resource value). The purpose of the list of strategies was to explore whether there are relationships between the perspectives and characteristics of the design professionals and their focus in terms of incorporated strategies. While participants without CE experience were considered able to answer questions on CE knowledge needs and effects in their organisations, they were excluded from questions that would require practical experience such as encountered challenges of circular design.

The primary aim of the study was satisfied through descriptive statistics performed in IBM SPSS Statistics version 29. To determine statistical significance, $\alpha = 0.05$ was used. A bivariate analysis was conducted to examine the relationships and potential correlations between variables in the survey modules organisational changes, experienced challenges, and needed knowledge for circular design. The purpose of this analysis was mainly explorative and to guide further investigation and discussion. An open-ended question regarding 'new networks and collaborations' resulted in 43 qualitative answers, which were further analysed and thematically clustered in NVivo (version 1.7.1) to gain a more detailed understanding of these efforts in practice.

To support the secondary aim of this study, seven metrics were developed which assess to what degree the participants incorporate circular design practices and capture their focus from different perspectives, emphasising different strategies in the framework. These metrics essentially enabled further investigation into whether design professionals who focus on certain (combinations of) strategies also share certain characteristics or perspectives. The metrics incorporated different weighting criteria for the strategies, based on the Circular Buildings Toolkit by (Ellen MacArthur Foundation and ARUP, 2022). To examine the foci of participants in relation to their characteristics, the defined metrics were used as dependent variables and the other responses were taken as independent variables. Each of the individual survey modules (characteristics of participants, circular design efforts, organisational changes, experienced challenges, and needed knowledge) was

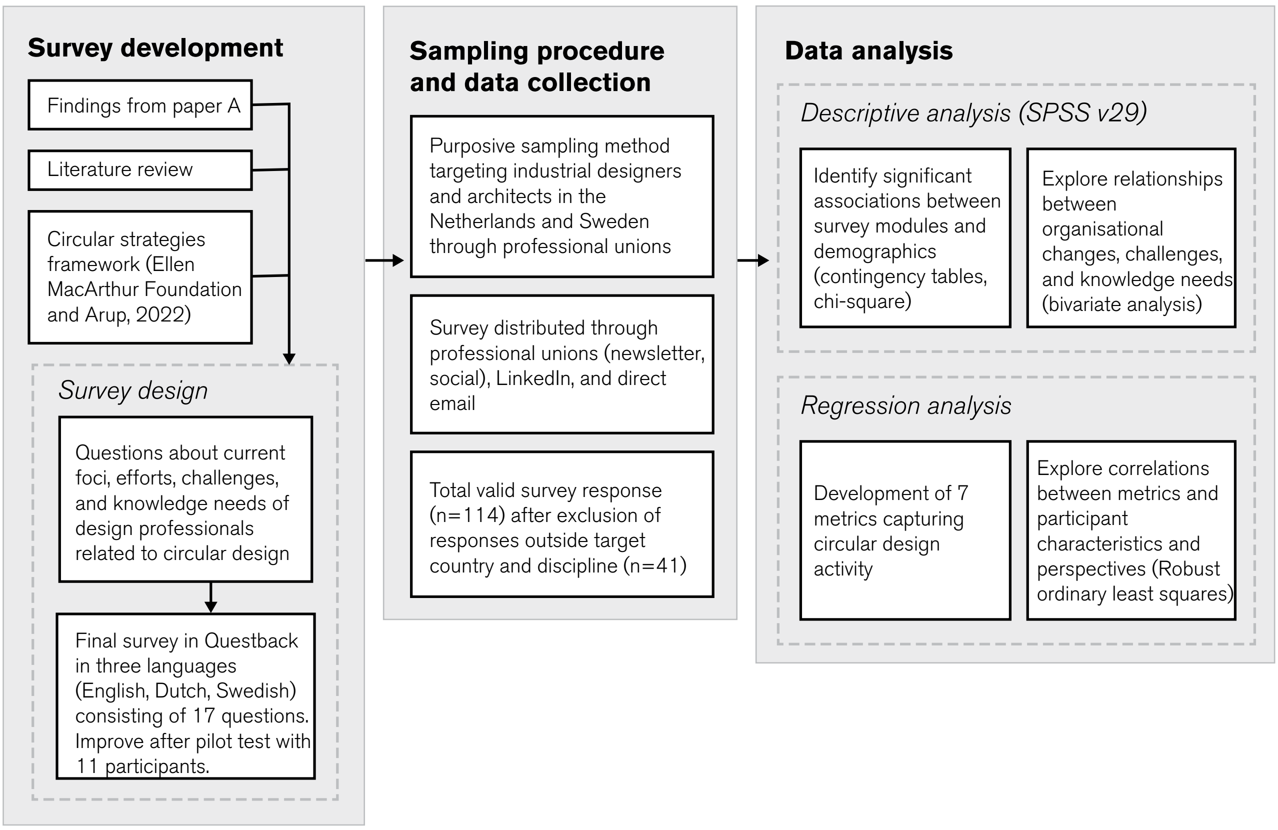


*Figure 10.* Overview of the research approach for paper B.

used as regressors to extract the most important factors within each module. All 114 responses were used in the regressions, and Robust Ordinary Least Squares was used to estimate the regression coefficients. Finally, the significant variables from each module were combined to understand the main contributing factors to the foci of the design professionals in terms of incorporated strategies. Overall, the purpose of the regression analysis was explorative and seen as a direction for further research and discussion. For a comprehensive description of the data collection and analysis procedures, see appended paper B.

### 3.2.2 Study 2: The role of co-creation in supporting design for a circular economy

Study 2 concerned a longitudinal case study of the four-year project The Circular Kitchen (CIK) in which academic and industry partners collaborated to develop kitchen solutions based on CE principles. The study investigated the role of prototyping and co-creation in supporting the COI process.

The researchers involved in the CIK project deployed participatory action research (Reason and Bradbury, 2008a) and collaborated with diverse actors to co-create the intended CE solutions, facilitate the shared knowledge generation process, and actively participate in the innovation trajectory. This enabled a comprehensive and systematic analysis of actions, views, and decisions throughout the entire process.

In a four-year innovation project, perceived challenges and the perspectives of actors are continuously changing throughout the different phases of the COI process. Therefore, a longitudinal analysis of the COI process was considered suitable to capture the diverse activities, perceived challenges, and stakeholder interactions over time. A detailed account of the Swedish CIK project encapsulating this longitudinal analysis can be found in Appendix A of this thesis.

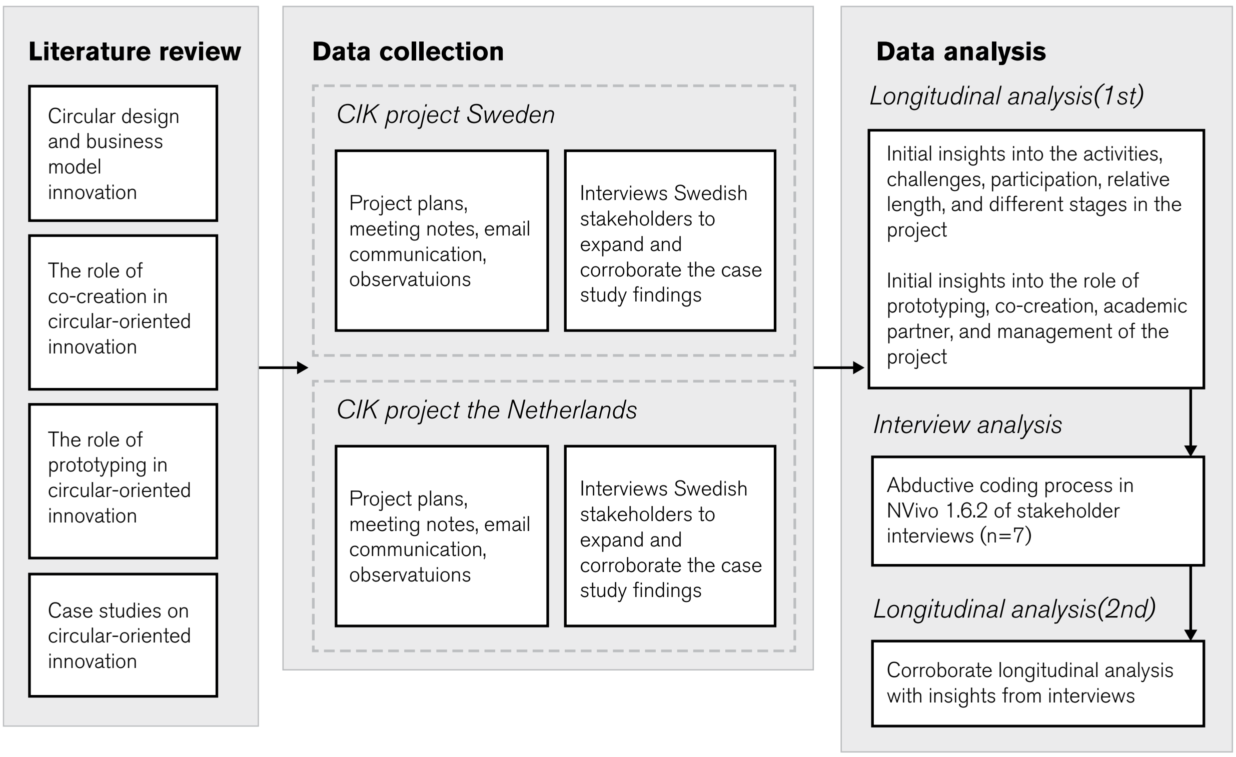


*Figure 11.* Overview of the research approach for paper C.

Based upon the longitudinal data collected by the researchers throughout the project, a timeline of events was constructed to support the longitudinal analysis and gather insights related to the aim of investigating the role of co-creation and prototyping throughout COI processes. Longitudinal case studies require the distinct step of the construction of a timeline of events or a sequence of changes in research variables across time, which are extracted from the data and are a basis for the case study narrative (Street and Ward, 2012).

Figure 12 provides an overview of the research approach which shows that after the initial longitudinal analysis, semi-structured interviews were carried out with project partners to corroborate the findings from the longitudinal analysis. The interviews aimed to gather additional insights from the perspective of the stakeholders who actively participated in the project, to corroborate the timeline and initial findings. An interview guide was developed covering questions related to experiences of the projects, the role of collaboration and prototyping, and perspectives on CE in the kitchen industry. The interviews were transcribed and coded in NVivo, after which iterative discussions took place between the authors to define and cluster the findings from the interviews into themes. Finally, the empirical results are compared with the existing literature on the role of prototyping and co-creation in COI.

### 3.2.3 Study 3: Supporting circular design through a card-based design tool

Study 3 resulted in two research outputs included in this thesis, papers D and E. Study 3 focused on exploring how circular design in practice can be supported through a card-based design tool which facilitates ideation and co-creation of holistic circular design solutions in collaborative and

*Table 1.* Overview of all workshops organised with the card-based circular design tool.

| Date | Participant background | Participants | Tool iteration | Relates to paper |
|---|---|---|---|---|
| 02-10-2019 | Industrial designers, mechanical engineers, interaction designers, architect from the region of Gothenburg, Sweden | 12 | Paper-based | Paper D |
| 20-03-2020 | Interior architecture students, industrial design students from a university in Stockholm, Sweden | 22 | Digital 1.0 (digital workshop) | - |
| 23-04-2020 | Industrial design students from an applied university in The Netherlands | 19 | Digital 1.0 (digital workshop) | - |
| 08-09-2020 | Architecture students from an university in Gothenburg, Sweden | 161 | Digital 2.0 (digital workshop) | Paper E |
| 06-11-2020 | Architect, mechanical engineer, product manager, real estate advisor, housing corpo-rations. Participants were all from the Netherlands. | 11 | Digital 2.0 (digital workshop) | - |
| 10-11-2020 | Architecture students of management in the built environment at a technical university in the Netherlands. | 106 | Digital 2.0 (digital workshop) | - |
| 19-11-2020 | Property developer, architect, professor, project managers. Participants were all from the Netherlands | 8 | Digital 2.0 (digital workshop) | - |
| 03-09-2021 | Architecture students from an university in Gothenburg, Sweden. | 140 | Digital 2.0 (digital workshop) | Paper E |
| 06-09-2022 | Architecture students | 144 | Digital 2.0 (physical workshop) | - |

workshop settings. The tool was utilised in various workshops with practitioners and students as a way of further examining and gathering knowledge about the process of designing for a CE (see Table 1).

Paper D focused on the development and testing of the Cards for Circularity (CfC), a card-based circular design tool, in a workshop involving design practitioners. Paper E concerned a further developed version of the CfC into a web-based digital tool which was utilised in two (digital) workshops over two years with students in architectural education. The following subsections will discuss the deployed methods in papers D and E in greater detail.

### A DESIGN WORKSHOP WITH DESIGN PRACTITIONERS AND RESEARCHERS (PAPER D)

The objectives of this paper were twofold: (1) to gather practical insights into design for a circular economy, and (2) to explore the potential of design tools, particularly CfC, in supporting the process of designing for a circular economy. Following a Research-through-Design (RtD) approach, the study emphasized the importance of design action in generating knowledge and was carried out by the designer-researcher (Stappers et al., 2014).

The research was conducted in several steps. Firstly, existing circular design methods were reviewed, and a card-based circular design tool, CfC, was developed. Subsequently, a half-day workshop lasting approximately five hours was organized, involving 12 design experts (10 practitioners and two researchers). The workshop included an interactive survey to evaluate the participants' current knowledge and practices regarding circular design. Additionally, a design workshop was conducted utilizing the CfC tool.

As a theoretical foundation for the design of the cards, the circular building components (CBC) generator was selected. This tool, which supports the synthesis of integrally cohesive circular design solutions, was developed based on a systematic literature review and analysis of 36 existing circular design frameworks (van Stijn and Gruis, 2019). It encompasses relevant

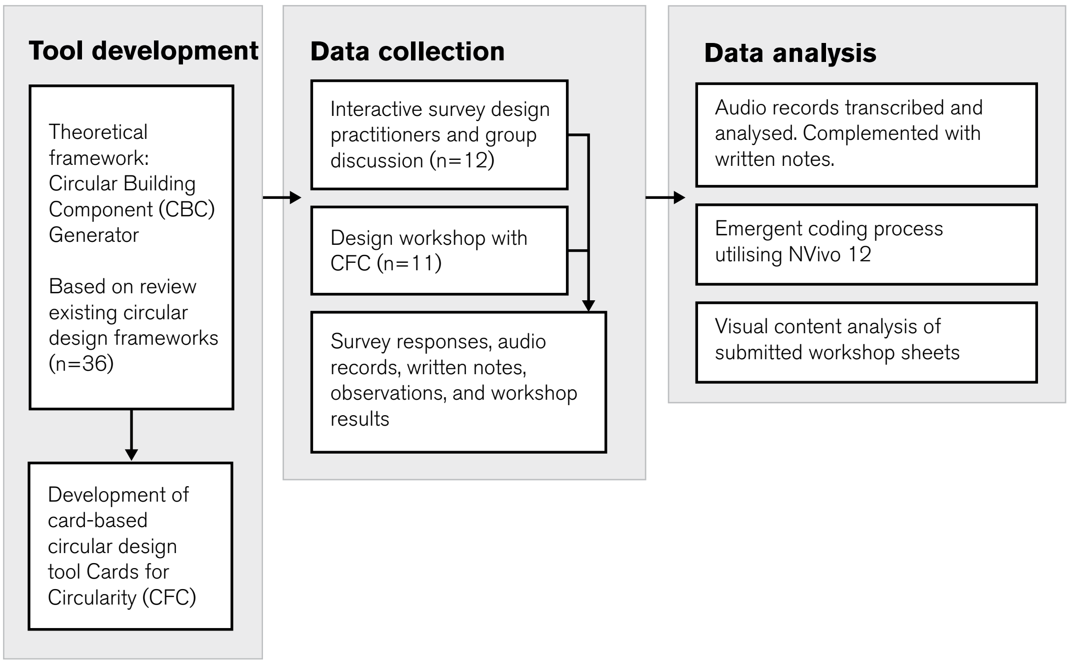


*Figure 12.* Overview of the research approach for paper D.

parameters regarding materials, lifecycle, design strategy, and financial arrangements.

The CfC tool comprises various cards representing design parameters related to circular design strategies, materials, and lifecycles. The cards are categorized into three colours: the technical model (relating to the physical design of the artefact), the industrial model (relating to value chain interactions), and the business model (involving marketing and financial aspects). The cards are designed principally to support ideation phases but can potentially be used in different stages of the design process (see paper D for a visual representation of the cards).

The workshop commenced with an interactive survey aimed at evaluating the participants' knowledge, experiences, and practices in designing for a circular economy. Mentimeter, an interactive polling tool, was employed to pose questions to the audience, focusing on circular economy knowledge, and challenges in promoting circularity in design practice and business. Following each question, a brief focus group discussion provided an opportunity for participants to share additional thoughts.

Subsequently, the interactive survey was followed by a design workshop lasting approximately 45 minutes. Participants were divided into three groups and briefed with designing concepts and ideas for kitchen furniture and appliances based on the circular economy concept, using the CfC tool. Each group received a printed set of cards (48 cards) from the technical model, representing various design options for parameters such as material, lifespan, lifecycles, and circular design strategies. Due to time constraints, the business and industrial model options were excluded from the workshop. Each group worked at separate tables, where the cards were pre-arranged on a map with different categories to provide structure and aid navigation. Data collected during the study included survey responses, audio records, written notes, and observations. Audio records were transcribed and analysed using NVivo 12 software. Through an emergent coding process, a list of first-order and subsequently second-order codes was generated, capturing attitudes, challenges, and enablers for circular design in practice.

### REFLECTIONS ON THE USE OF THE CARDS FOR CIRCULARITY IN DESIGN EDUCATION (PAPER E)

The paper aimed to investigate how architecture students currently interpret the CE concept and how they apply circularity principles in a design assignment using the CfC. Compared to paper D, two major changes were made to the CfC: (1) the inclusion of practical examples on the cards to inspire, broaden perspectives and convey the practical feasibility of the CE and (2) the change to a digital web-based version of the tool to enhance accessibility for digital workshops (amid the COVID-19 pandemic) and enable simultaneous usage by a large number of groups in the context of design education. See Figure 13 for a depiction of the web-based CfC. A tab menu allows the user to navigate through four different phases of the workshops (orientation, selection, ideation, and finalization).

The half-day workshops (approximately 5 hours) took place entirely over the online communication platform Zoom and started with a poll to evaluate the participants' knowledge and interpretation of the CE. Afterwards, a half-hour lecture addressed the CE concept, and design for a CE, and introduced the CfC. Following, the participants were randomly distributed

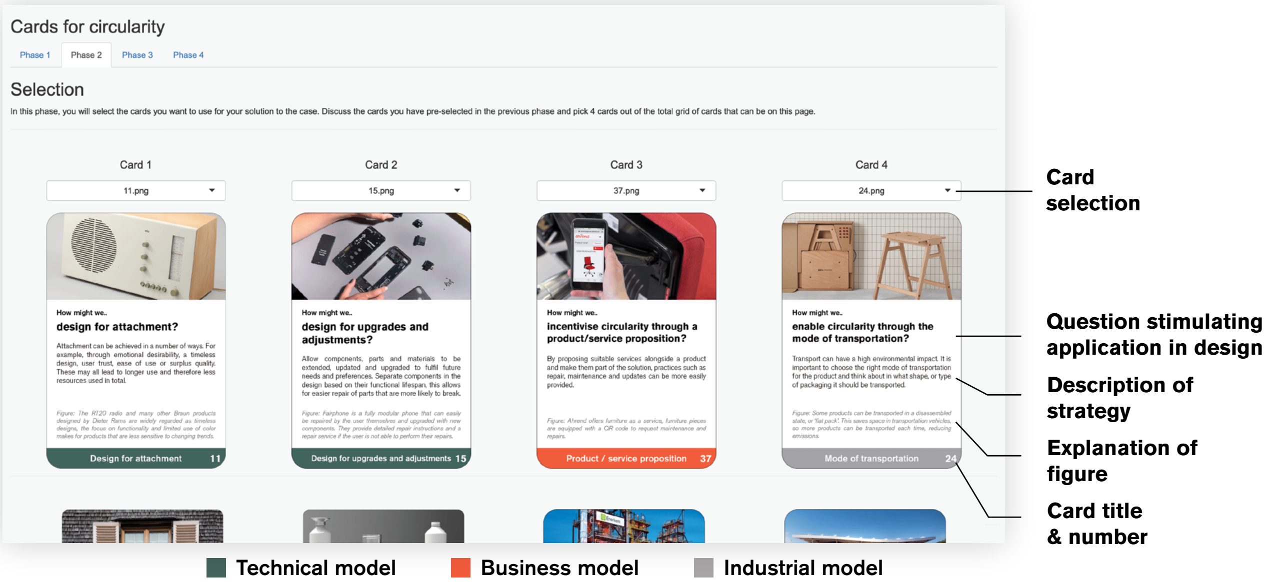


*Figure 13.* Impression of the web-based design tool Cards for Circularity (CfC) illustrating the layout of the cards in the selection mode.

in groups of 3 to 5 people through the ‘Breakout rooms’ functionality in Zoom before the start of the workshop. The groups were assigned one out of six design cases that each represented a different level of scale, complexity, and evolution through different timescales, based on the shearing layers by Brand (1994). The groups were provided with a workshop manual document describing the four different phases of the workshop in further detail, corresponding to the four phases in the tool. A complete overview of the CfC toolkit including an overview of the cards and the workshop manual can be found in Appendix B.

Using the classification of the shearing layers for the different design cases enabled us to explore whether and how the different cases (and different scale and time perspectives) affected the choice of design approach and strategies (i.e., card selection). Each group was assigned a collaborative board in the online whiteboard tool Miro to capture thoughts, notes, and sketches

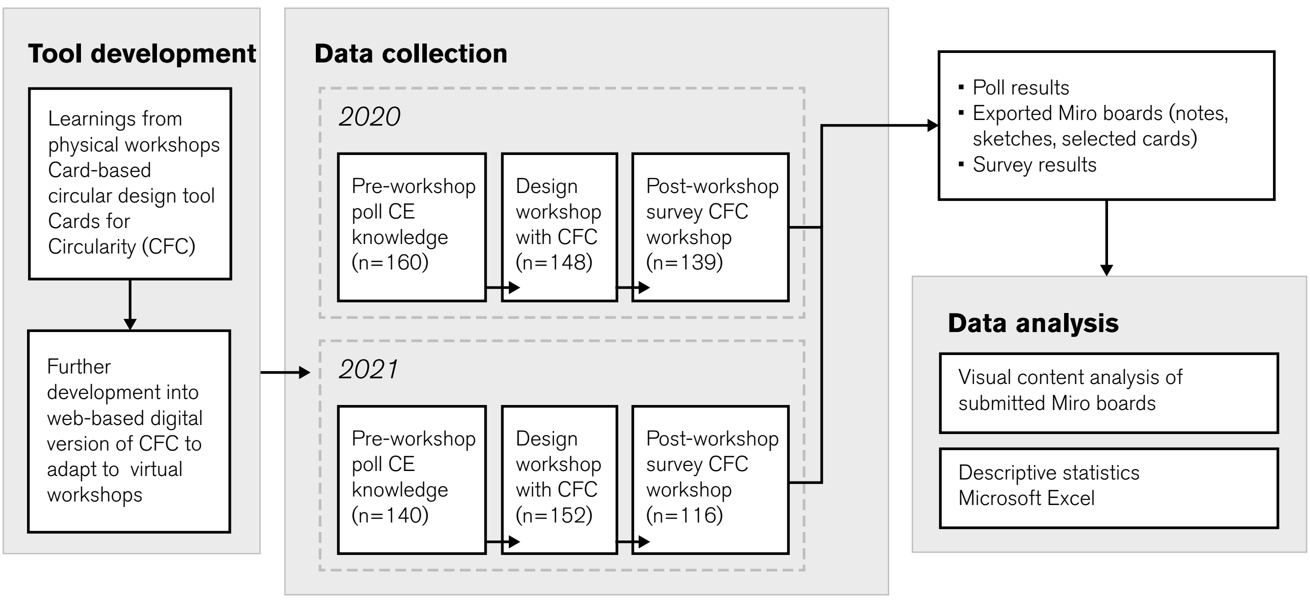


*Figure 14.* Overview of the research approach for paper E.

during the design process. The researchers made observations of the students by periodically assessing the Miro boards and consulting the breakout rooms during the workshop, and after the workshop, all Miro boards were visually evaluated.

After the design assignment, the researchers organized a debriefing session where some groups were invited to present their concept to the entire group and participants had the opportunity to reflect on the workshop and share thoughts. A post-workshop survey was conducted through the software Questback to evaluate the participants' (1) experiences using the tool, (2) experiences of the design workshops, and (3) thoughts and reflections on the processes of designing for a CE.

The data collection consisted of exported Miro boards, poll results, and survey results. Each Miro board was analysed, and relevant data was extracted (card selection, designed solution) and imported into Microsoft Excel alongside the results of the poll and survey for further analysis.

## 3.3 Reflections on the methodology

The following section reflects on the chosen methodology employed in this thesis work, which aimed to understand and advance circular design in practice. The thesis adopted a pragmatic paradigm, allowing for a flexible approach emphasizing problem-solving and multiple perspectives, aligning well with the aims of the research and the background of the researcher. The methodology encompassed both the use of qualitative and quantitative methods to provide a comprehensive picture of the topic and the mixed-methods approach allowed for triangulation and enhanced the credibility and validity of the findings.

The primary focus of this thesis was on empirical research, allowing for an in-depth exploration of design and innovation processes for a CE based on real experiences. Through engaging with designers and practitioners directly, the aim was to gain first-hand insights into their perspectives and experiences. By engaging in the process of designing for a CE (through the participatory action research and RtD approach) rich and contextual data was gathered capturing the nuances and complexities of developing solutions for a CE. During the initial stages of the research, the researcher was promptly involved in a COI process (the CIK project) and directly encountered the challenges of co-developing circular value propositions, with sparse time for literature research and performing theoretical groundwork. This instigated an explorative and inductive research approach (i.e., interview study A) to better understand the practical implications of designing for a CE. This allowed for the emergence of patterns and new concepts directly from the data, without being constrained by preconceived theories and predetermined categories of analysis (Patton, 2002b).

While qualitative approaches have faced criticism for their perceived lack of rigour, and inductive research has been questioned for its ability to demonstrate scientific advancement (Goldthorpe, 2000), there are ways to enhance qualitative rigour through systematic methodologies. One such methodology, developed by Gioia, Corley, and Hamilton (2013), offers a means to improve the process of inductive reasoning and the development of new concepts. In Study A, this methodology was employed for data gathering and analysis, providing several advantages. Firstly, it allowed for an informant-centric approach or first-order analysis, which prominently showcased the voices of the interviewees and facilitated the discovery of new concepts. Subsequently, a second-order analysis was conducted, utilizing researcher-centric concepts, themes, and overarching theoretical dimensions. Study A was followed up by a quantitative study (study B) to examine whether the findings were represented on a wider scale and allow for generalisation and triangulation.

It should be noted that due to the prioritisation of an inductive approach initially and the focus on empirical research, less emphasis was placed on investigating and selecting suitable theoretical frameworks. While appropriate theoretical frameworks undoubtedly would have provided a lens through which the findings could be interpreted and enriched, the thesis focused primarily on capturing the realities and intricacies of design practice itself. However, theoretical underpinnings were not entirely disregarded; rather, they were incorporated where necessary to support and contextualize the empirical findings.

The pragmatic approach towards this thesis work comes with several limitations. One limitation is that the focus on practicality and real-world application somewhat limited the theoretical grounding and theoretical contribution of the thesis, yet the practical impact and contribution of this research were promoted. Due to the combination of the research paradigm (pragmatic), the interdisciplinary nature of the research (transdisciplinary), and the subject (sustainability/circularity), the research has been difficult to navigate. While a stricter theoretical framework could have enhanced the rigour, preciseness, and validity of the research, the pursued approach allowed for integrating and connecting diverse perspectives which provided fruitful avenues for further research.

Diving into the topic of design and innovation for a CE with the ambition of gaining a holistic picture, inherently means that the researcher touches upon diverse fields (e.g., business and management studies, supply chain management, innovation management, industrial ecology) that can be considered outside the typical 'domain' of a design researcher. Nevertheless, the design researcher can contribute by looking at it from a design angle and design process perspective and contribute with approaches derived from designerly ways of knowing and doing (Cross, 1982).

Another limitation is the scope and evaluation of the research. Due to the focus on problem-solving and practical outcomes, the research may have overlooked broader socio-cultural and critical viewpoints (e.g., critical reflections on how the CE concept supports sustainable development and potential alternative viewpoints and directions).

One potential weakness of this thesis relates to the participatory action research through which knowledge was gathered and generated, which holds the (inherent) risk for subjective bias and implies that the research process and outcomes were actively influenced by the researchers. Reason and Bradbury (2008) point out that the major challenge of PAR in the context of PhD work is how to maintain deep involvement and the reflective distance, capturing the richness of the active engagement in the social change process, while at the same time lending enough weight to the researchers' critical distance to the process he or she has been engaged in. As much as possible, through a process of reflection and action, the researcher has attempted to extract knowledge and insights from the gradual learning process. Another action that was taken to address this during the data collection process was to complement the interpretations and observations of the researcher with the perspectives of other participants and stakeholders (e.g., through interviews).

An alternative approach would be to exclude the researchers from actively participating in the innovation process, for example by observing it through ethnographic methods, while the involved stakeholders and companies would own and direct the development process. While this might have generated different results and potentially omitted some of these challenges, the active participation of the researchers contributed to the change process and was highly appreciated by the stakeholders as it added capacity and knowledge to the innovation process, and allowed for the co-generation of knowledge which was negotiated between the scientists and problem-owners (Gibbons et al., 1994).

It is important to acknowledge that the field of DfS is thoroughly researched and well-established, and there is good reason to incorporate (past) lessons from both within and outside the discipline of sustainable design (Lofthouse and Prendeville, 2018) when examining design for a CE. Therefore, an alternative abductive approach to this research would have been appropriate and could have started with an extensive literature review of DfS, to develop a theoretical framework to study design practice, which would enable the refinement of existing theories and ideas into the context of the CE. Instead, DfS literature was examined thoroughly to contextualise and support the empirical findings. One can also argue that circular design requires new inquiries into necessary design knowledge and approaches, considering the fundamental differences between existing relative approaches to sustainable design (e.g., eco-design) that focus on mitigating environmental issues, versus absolute approaches (circular design) that focus on resolving them (den Hollander et al., 2017). In addition, the rapidly changing technological, environmental, and social paradigms might also mean that design strategies and guidelines from two decades ago are not necessarily as valid and relevant today (Bakker et al., 2021), and the landscape of design practice in general has drastically changed in recent decades (Meyer and Norman, 2020).

# 4. Summary of results

The following section summarizes the main results of the three studies included in this thesis. The section is structured according to three studies (1-3), including subsections that summarize the findings of the individual papers. For a more detailed description of the results, see the corresponding publications. The chapter concludes with a comparison of the findings, highlighting the differences and similarities between the results of the different studies.

## 4.1 Study 1: Exploring circular design in practice

The results of study 1 provide insights into how design professionals within architecture and industrial design currently interpret and implement the concept of a CE in design practice. In addition, the section reports on the main challenges and knowledge needs of design practitioners concerning circular design.

### 4.1.1 Interviews with industrial designers and architects

The findings of paper A provided several insights regarding (1) the circular design process, (2) the effects of the CE on design agencies, (3) the changing role of the designer, and (4) the external factors affecting circular design in practice (see Figure 15 for an overview of the findings).

### THE CIRCULAR DESIGN PROCESS

In both the context of industrial design and architecture, the participants pointed out the increased complexity of design projects with circularity as a focal point, due to a multitude of reasons. First, designing for a CE requires extensive knowledge of materials, ecology, environmental assessment, stakeholder management, business models, and value- and supply-chains. This is addressed by involving experts early in the design process and expanding disciplinary knowledge. Second, closing resource loops requires the involvement and management of additional stakeholders in the design process. Third, a more extensive initial research phase is needed in design projects to create a deep understanding of the supply and value chains involved and grasp the entire system related to the project. Overall, these factors extend the length, costs, and overall scope of the design process.

Participants pointed out the role of new (digital) technologies when designing for a CE, such as material passports and digital twins. Physical artefacts increasingly turn into 'living' assets that can both be embedded with information about their composition and provide feedback about their condition and treatment. This enables designers to better understand actual product and building lifecycles and helps them to define better interventions for lifetime extension and resource recirculation.

Circularity in the built environment appeared to be strongly associated with the reuse of obsolescent materials and components (especially from the market demand side), and the architects currently emphasize this strategy in practice because it is an easy way to engage with circularity, it reduces costs, and it is better for the environment to reuse old materials rather than new ones. The implications for the architectural design process are that a level of flexibility and equivocality needs to be integrated due to the uncertainty of what spare building materials and components will be identified, mapped, and collected during the 'inventory' process.

For industrial designers, the design process in the context of a CE becomes increasingly system- and service-centred rather than object-centred. Circular product design relies on the design of systems, these include the design of a product, a business model and services that capture value of product lifetime extensions and resource recovery. Concretely described strategies utilised in the design process were upcycling and making products modular and parts exchangeable to (1) enable recycling, refurbishing and repairing practices; (2) promote take-back schemes; and (3) adapt to the demands and preferences of different users.

### THE CHANGING ROLE OF DESIGNERS IN A CIRCULAR ECONOMY

The participants described how value chain collaboration is crucial in the context of a CE to connect different stages of a product or building lifecycle. Therefore, stakeholder collaboration and management, and the involvement of all relevant actors early in the design process, becomes more important. Agencies take an active role in establishing connections between clients, suppliers, manufacturers, and other actors in the value chain. Furthermore, they take an active role in facilitating collaboration for a CE; one example given was that of a collaborative platform that invites different actors, unlikely partners, or competitors to an intensive co-design process or ‘design sprint’ to address larger environmental and systemic questions together and challenge the traditional silo thinking that exists within individual organisations.

Both industrial designers and architects emphasised that designing for a CE requires extensive business understanding and economic knowledge to be able to design and convince clients of circular value propositions, the financial benefits of which are typically only apparent when considering extended or multiple lifecycles of products and buildings. Circular product design relies on the combination of the physical design and the business model, which requires that both aspects are simultaneously considered and developed early in the design process.

The finding indicated the role of designers as change agents in the context of the CE. Some of the projects described by participants were less about the actual design of artefacts and more about challenging the existing ‘linear’ mindset and making circularity questions and challenges tangible and actionable. The participants in the study found it generally important to raise awareness and understanding of the CE and utilised various strategies (e.g., sharing successful cases; showcasing projects and exhibitions, infographics, and storyboards) to elevate the CE from a conceptual discussion to a tangible and actionable one, thereby, creating alignment between the designer and client and internally within organisations.

## EFFECTS OF THE CIRCULAR ECONOMY ON DESIGN AGENCIES

One effect of the CE on design agencies has been the assembly of dedicated internal teams or research ‘labs’ within the larger organisations of the study that are specifically focused on circular design. According to the participants, this enables agencies to investigate CE-related knowledge

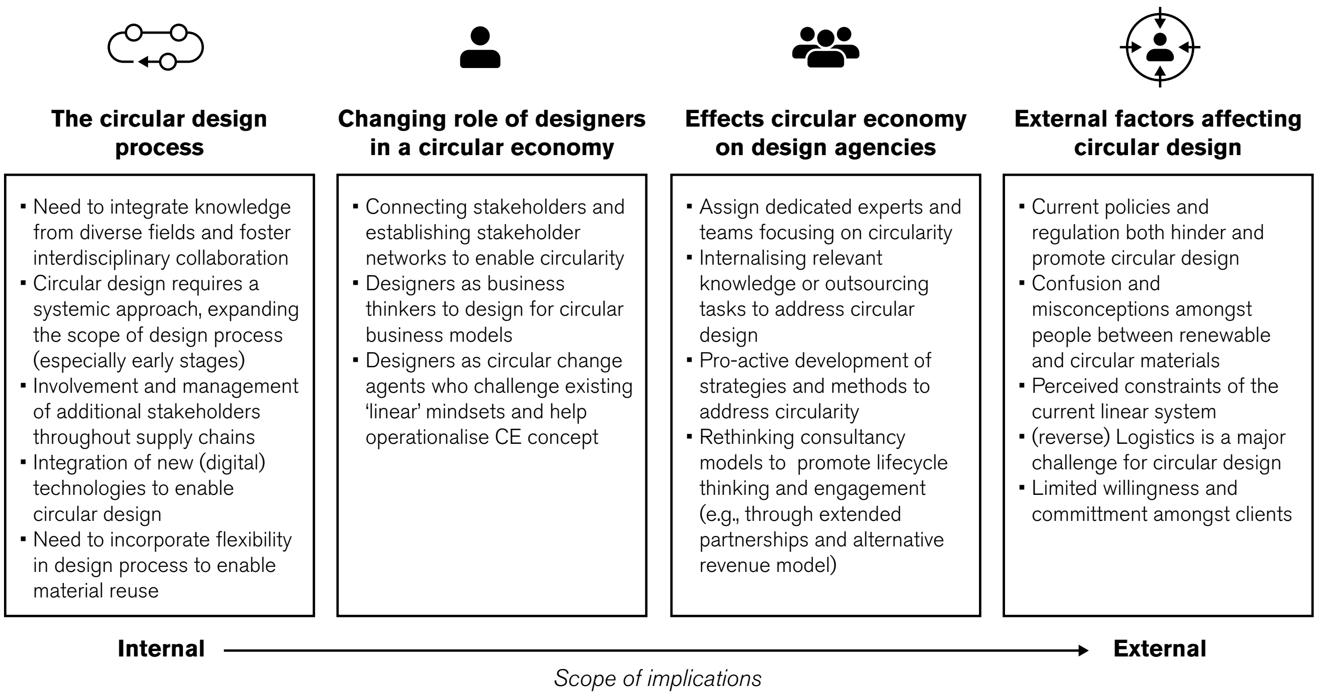


*Figure 15.* Overview of main implications of the CE in design practice as identified in Dokter et al. (2021).

gaps and explore ideas for which clients are not willing to pay. In addition, when knowledge gaps are encountered, external experts may be included in the design process (e.g., biologists to enhance the biodiversity of a building design); if knowledge gaps are structural or pivotal to design choices (e.g., LCA assessment), additional knowledge may be deliberately internalised.

Another effect identified was that agencies are questioning to what extent the conventional consultancy models support agencies in engaging with circularity and the ecological challenges in product and building design. Participants described how design still most often involves temporary efforts and engagements between designers and clients, which neither encourages lifecycle thinking nor long-term engagement of designers with the lifecycles of designed artefacts. Both architects and industrial designers stressed the importance of extended partnerships and alternative revenue models.

Finally, the participants highlighted the lack of knowledge available on ways to implement circularity in practice and, therefore, actively develop tools, methods, and documentation to support the circular design process and tackle CE-related challenges in projects.

#### EXTERNAL FACTORS AFFECTING CIRCULAR DESIGN IN PRACTICE

Several external factors (i.e., beyond the control of designers) were identified that affect possibilities for circular design. Current policies and regulations seemed to both hinder and facilitate circular design. For example, regulations for quality insurance of building components seemed to hinder reuse practices for architects, while stricter regulations regarding environmental impact assessments seem to stimulate designers to lower environmental impacts and create equal responsibilities amongst designers to adhere to such practices. Challenges regarding materials were identified, related to reverse logistics and recirculation of materials, and confusion and misconceptions amongst clients and consumers about circular materials. Finally, the limited willingness of clients was considered a hindrance to circular design, which related to the associated costs and risks of circular design approaches, and the perceived constraints of the current linear system.

### 4.1.2 Survey with industrial designers and architects

Paper B focused on investigating the current foci, efforts, challenges, and knowledge needs of design professionals related to circular design. In addition, a secondary aim of the study was to explore what relationships exist between the perspectives and characteristics of the design professionals and their focus in terms of circular design.

#### CURRENT FOCI OF DESIGN PROFESSIONALS REGARDING CIRCULAR DESIGN

Paper B provided insights on the current foci of design professionals regarding circular design, assessed by the design strategies the participants have incorporated in CE-focused projects. The results (see Figure 16) show the incorporated design strategies in projects, distinguishing between design disciplines and whether the participants had experience with CE-focused design projects. Particularly the strategies S5 ‘Design for disassembly’, S6 ‘Increase material and energy efficiency, and S11 ‘Incorporate circular services and business models’ were significantly more frequently incorporated in design projects focusing on CE (using $\alpha = 0.01$). Furthermore, the

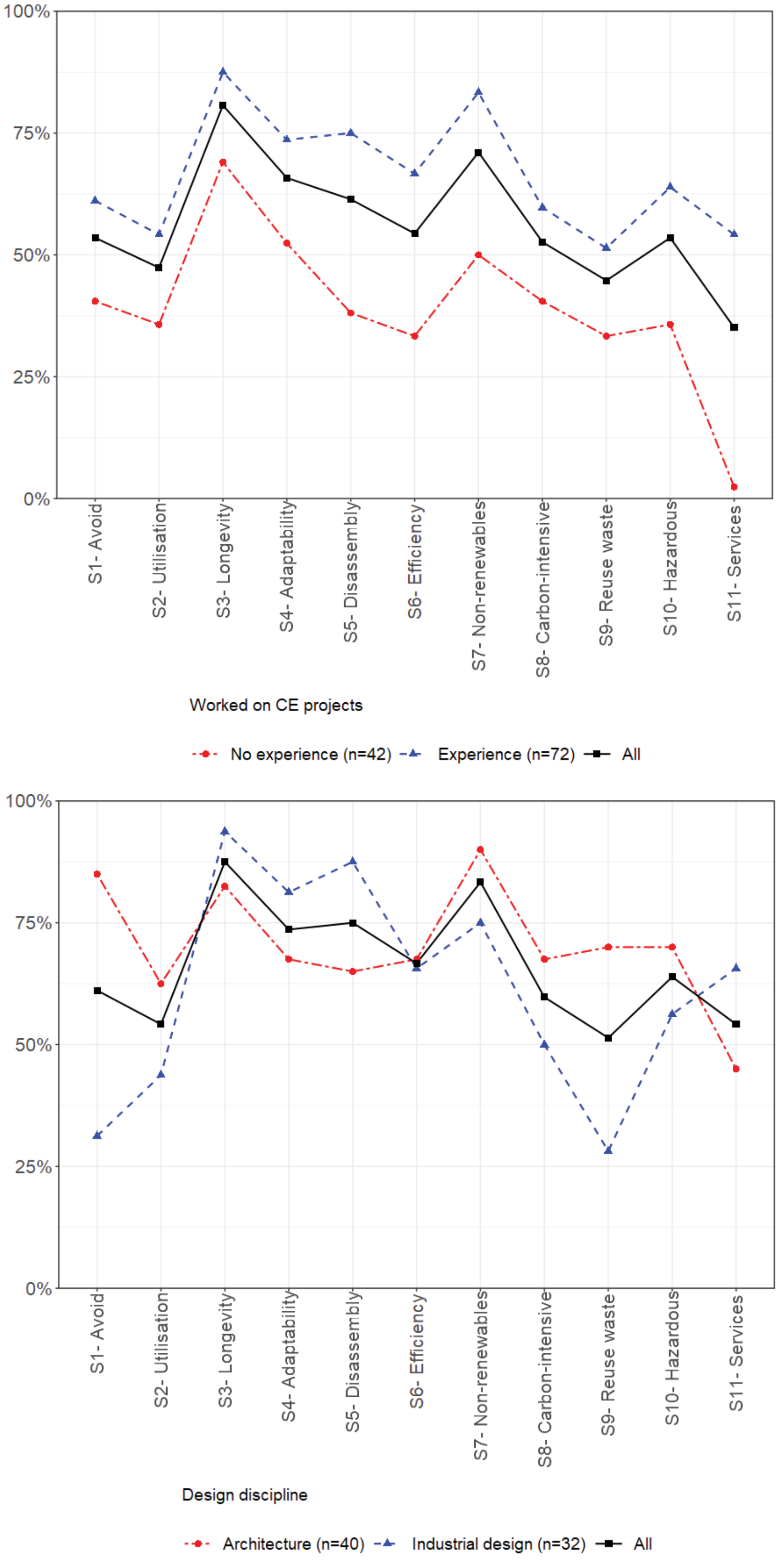


*Figure 16.* Design strategies incorporated by participants with and without CE experience (left), and design strategies incorporated by industrial designers and architects in CE projects (right).

results indicated that architects, compared to industrial designers, more frequently incorporate strategies focusing on avoiding new construction and reusing waste or spare materials for new buildings. Industrial designers on the other hand, more frequently incorporated strategies relating to design for longevity, design for adaptability, design for disassembly, and circular services and business models.

### CURRENT EFFORTS, CHANGES, CHALLENGES, AND KNOWLEDGE NEEDS IN RELATION TO CIRCULAR DESIGN

The results provided an overview of the organisational changes, efforts, challenges, and knowledge needs experienced by design professionals in relation to designing for a CE (see appended paper B for full details). Regarding organisational changes, the perspectives of industrial designers and architects were similar, with the main organisational changes relating to (1) identifying new materials, techniques and technologies that support the circular design of products and buildings, (2) developing methods, strategies, and tools to address circularity within the design process, and (3) new networks and collaborations outside organisations. The open-ended follow-up question posed to respondents replying positively to new networks and collaborations, revealed diverse answers. Architects highlighted various regional initiatives for circular building, collaborations with universities and research institutes, suppliers and platforms for reused materials, circular dismantling companies, and experts on diverse topics (e.g., sustainable installation, construction, and building). Industrial designers reported dedicated industry networks, network initiatives on a regional and EU level, and collaborations with research institutions, experts, manufacturers, and material suppliers.

Findings related to the current efforts of design professionals showed that most architects and industrial designers already use tools and methods that support circular design. Moreover, 40% of the industrial designers and 49% of the architects reported performing circularity assessments of different proposals during the design process. A notable difference between architects and industrial designers was that the architects appeared to be more active in co-creating solutions together with stakeholders and involving a wider network of value chain stakeholders in projects. Furthermore, the majority (60%) of architects agreed that the CE requires different business models for rewarding design work, while only 32% of the industrial designers agreed with this statement.

The most prevalent challenges when designing for a CE were (1) Business aspects and financial feasibility, followed by (2) Limited willingness of companies to invest in circular solutions, and (3) Estimating environmental impacts over the entire lifespan. One notable difference was the challenge of ‘Current regulations and policies’, which was significantly more often reported by architects.

The architects and industrial designers had similar perspectives on what knowledge is needed to design for a CE; the results revealed no significant differences. The participants emphasized the need for knowledge to deal with technical challenges such as (1) material knowledge, (2) environmental impact assessment, and (3) economic assessment methods. Interestingly, no significant differences were found between the needed knowledge and the country, organisational size, and years of professional experience of the participants.

CHARACTERISTICS AND PERSPECTIVES OF DESIGN PROFESSIONALS ACTIVE WITH CIRCULAR DESIGN

A set of metrics was developed to examine to what extent design professionals incorporate circular design strategies. Through a regression analysis incorporating these metrics, insights were generated about the perspectives and characteristics of the design professionals that incorporate certain design strategies and show higher levels of CE activity.

The results indicated that the design professionals who were highly active in terms of incorporating circular design strategies were characterised by both the use and the development of tools and methods for circular design. Other factors that were also significantly associated with higher levels of CE activity were whether the participants undertake material research efforts and whether they have established new networks and collaboration to adapt to CE.

A noteworthy finding was that strategies associated with lifetime extension particularly showed a positive correlation with tool and method development, while strategies focusing on building with the right materials were positively correlated with material research. The results also indicated that industrial designers had a negative correlation with strategies regarding avoiding new construction and production, suggesting industrial designers are less active with these strategies.

Finally, it should be noted that factors related to organizational goals for working with CE, whether CE is widely demanded by clients, or the extensive involvement of stakeholders in projects were not identified as significant factors for the level of activity regarding incorporated circular design strategies.

## 4.2 Study 2: The role of co-creation and prototyping in circular-oriented innovation

Study 2 aimed to provide a longitudinal perspective on how companies go through the process of COI and increase the understanding of how prototyping and stakeholder co-creation can be utilised to support the innovation process. Study 2 is primarily based upon case-based evidence extracted from the CIK project and resulted in paper C. The following section provides a summary of the main findings of study 2 (see appended paper C for a more detailed account of the findings).

### 4.2.1 Co-creation in the case of the circular kitchen

Early co-creation workshops between researchers, the kitchen manufacturer, and social housing associations (as potential customers) provided a platform for co-developing the physical design of the circular kitchen, discussing concrete options for CBMs, and determining the roles and activities of actors within the CBMs. The results indicated that co-creation workshops supported the COI trajectory as they (1) guided the direction of the project, (2) enabled shared CE learning and network building, (3) verified the market demand for a circular kitchen which gave confidence to the kitchen manufacturer to pursue further development, and (4) made it possible to develop solutions together tailored to the demands and wishes of the parties involved.

The case study indicated that the initial stages of the innovation process are crucial; the early involvement of the supply chain and dedicated time are needed to enable shared learning, network building, and a comprehensive project vision before the co-design of solutions and prototyping to ensure a viable circular value proposition. Co-creation workshops organised with individual companies (i.e., the kitchen manufacturer) were found helpful in raising CE awareness and identifying opportunities for a circular value proposition. Yet, it was found difficult to further develop and convey the viability of the value proposition without the perspective and active engagement of the entire supply chain (involved in the production, installation, use, and end-of-life) that would be necessary to realize a kitchen based upon CE principles.

Throughout the project, the researchers facilitated co-creation workshops depending on the purpose and stage of the innovation process (for more details, see the timeline in paper C). Early co-creation workshops involved creative assignments (e.g., through printed workshop sheets) in which diverse stakeholders, company representatives and top-level management (i.e., CEOs) were incentivised to exchange thoughts and ideas from respective backgrounds and perspectives. This initially ensured a holistic perspective on circularity related to the products, business models, and the kitchen industry. Later in the project, the co-creation sessions were more focused on guiding the project, product development and prototyping, and ensuring stakeholder perspectives were

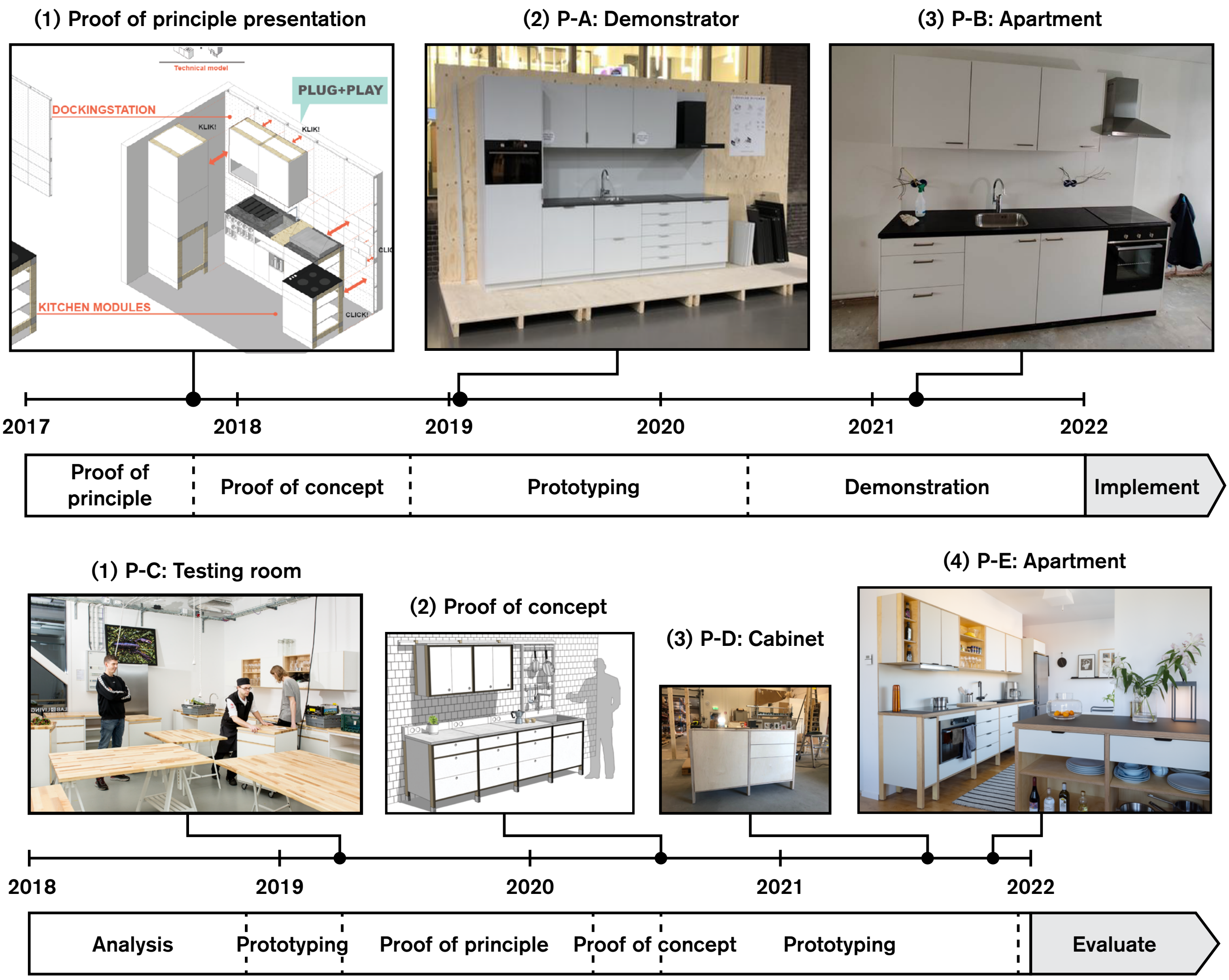


*Figure 17.* Overview of design outputs during the Dutch project (upper timeline) and Swedish project (bottom timeline).

ongoingly considered.

The paper provided three key lessons for co-creation in COI. First, partly due to the ambiguous and comprehensive project aim, stakeholders had diverse expectations and intentions, which led to strong fluctuations in project commitment and collaboration. Therefore, articulation and alignment of project expectations, commitment, and a shared project vision is essential. Secondly, co-creation depends on the willingness to collaborate with the supply chain. While some project partners initially did not fully see the benefits of actively collaborating with supply chain actors, others developed this willingness throughout the project as their CE awareness increased, and they increasingly saw circularity as a systemic and industry-wide challenge. Lastly, the presence of a 'neutral' facilitator and platform (in this case the universities) for the collaboration was considered important, as this addressed stakeholders' concerns regarding (external) collaborations and challenged them to rethink their supplier-client relationships.

### 4.2.2 Prototyping the circular kitchen

Paper C provided several insights regarding the role of prototyping in COI, and illustrated how the process of prototyping supported the overall collaboration and co-creation between stakeholders in the project. Aside from the generic role of prototypes in supporting the proof of concept, the paper identified three additional roles of how prototyping supported the COI process. The results indicated that in the context of COI, prototyping supports the process by making the concept of a CE tangible for the stakeholders, facilitating knowledge exchange between project partners and external stakeholders, and fostering stakeholder collaboration and circular supply chains.

Three key lessons for prototyping were extracted from the case study, which emphasised that it is vital to align expectations and purpose of prototypes between project stakeholders, ensure sufficient prototyping and experimentation capabilities and facilities and that linking prototypes to concrete project deliverables holds a risk for 'prototype fixation', fragmented solutions, and missed opportunities for shared value creation. The insights gathered about the role of prototyping and the extracted lessons were concerning particular prototypes, of which a timeline-based overview is presented in Figure 17 (see paper C for more a detailed explanation of the role of the specific prototypes).

## 4.3 Study 3: Supporting circular design through a card-based design tool

Study 3 focused on the development and testing of a card-based design tool which facilitates ideation and co-creation of holistic circular design solutions in collaborative and workshop settings. The tool was utilised in various workshops with practitioners (paper D) and students (paper E) and provided insights into the process of designing for a CE.

### 4.3.1 Workshop with design practitioners

Paper D addressed the development of the card-based circular design tool CfC which was utilised in a workshop with design experts to (1) derive key learnings on circular design in practice and

(2) explore how the CfC could support the process of designing for a CE.

## INTERACTIVE SURVEY AND GROUP DISCUSSION WITH DESIGN EXPERTS

An interactive survey organised with design experts revealed that the participants considered circular design foremost as a strategic challenge (e.g., 'setting up collaboration and aligning stakeholders' and 'finding sustainable business models') but also as a technical challenge (e.g., 'estimating the environmental impact of solutions over multiple lifecycles' and 'finding sustainable materials').

Other challenges related to designing for a CE mentioned by the participants were maintaining a holistic perspective, anticipating the consequences of design choices (e.g., material selection), a lack of designer involvement once products are on the market, and clients that are unwilling to explore circular solutions due to associated costs and changes to existing structures and operations.

To advance circular design efforts the participants pointed out several directions: (1) designers can take an active role in educating and engaging clients with CE, (2) an overview of successful case studies and examples would help to leverage circular design, (3) designers need deeper knowledge on business models, material alternatives, and EoL scenarios, and (4) engage with stakeholders on a regional level such as material experts and recycling facilities.

## RESULTS OF THE DESIGN WORKSHOP UTILISING THE CARDS FOR CIRCULARITY

Overall, the participants found the cards helpful in supporting idea generation and discussions on possible strategies to enable a circular product design. The groups picked and discussed different cards, and made considerations regarding the user context, technical aspects, and life-cycle related aspects such as the average and optimal lifespan of different materials and components they considered (see appended paper D for the produced results by the groups).

*Figure 18.* Depiction of the map with cards (left) and one of the groups during the workshop (right).

The design task was considered challenging within the time frame of an hour. The participants found the number of cards overwhelming and the different parameters too complex, which obstructed decision-making and the overall ideation process. While it was apparent that the cards individually provided a structured and actionable format, how all cards were presented at once on the map (see Figure 18) increased the complexity and cognitive load.

The participants found the cards addressing temporal aspects (lifespan, number of lifecycles) especially difficult, and making estimations regarding the lifespan of a concept would require material experts and contextual knowledge. Participants critically questioned whether a product design concept can be given the qualification 'circular' as a concept in itself does not enable 'circularity'; it would require further assessment to compare ideas on their potential to facilitate circularity. In addition to the generative function, the cards were found to support participants with diverse perspectives and knowledge about CE to discuss strategies, find consensus, and together translate selected strategies into concrete ideas.

### 4.3.2 Workshops with students

The following section summarizes the findings of paper E, in which the CfC was further developed and utilized in design workshops with architectural students. The purpose of the study was both to understand how architectural students interpret the CE concept, and how they apply CE principles in a design assignment using the CfC.

#### STUDENTS' INTERPRETATION AND KNOWLEDGE RELATED TO THE CIRCULAR ECONOMY

While the (self-reported) CE knowledge level was comparable in both 2020 and 2021, more than double the number of students had experience with the CE in design projects in 2021 (32%) compared to 2020 (14%). Students were asked what they see as the main goals of a CE, which revealed that they most frequently emphasized (1) reusing waste materials, (2) decreasing the environmental impacts of buildings, and (3) decreasing the use of non-renewable materials. Lifetime extension and decoupling economic growth from resource consumption were considered to a lesser extent. When asked what knowledge would enable the students to become better at designing for a CE, the students in both years showed agreement and most frequently emphasized better material knowledge and circular design methods and tools (with around 20-25% of the responses). Fewer students pointed out knowledge related to business and economics, environmental impact assessment, and stakeholder collaboration (between 10-15%).

#### RESULTS OF THE DESIGN ASSIGNMENT USING THE CARDS FOR CIRCULARITY

During the design assignment, the students were assigned different cases and made collaborative decisions on which cards to work with (each group selected 4 cards). In total, 300 cards were selected, 161 in the technical model (54%), 59 in the industrial model (20%), and 80 in the business model (36%). The results indicated that the distribution of cards over the three models differed per case. For instance, the apartment case was associated with a greater focus on technical cards, while the furniture piece was associated more with industrial cards. Interestingly, in both 2020 and 2021, the same cards were frequently selected and related to design for standardisations and

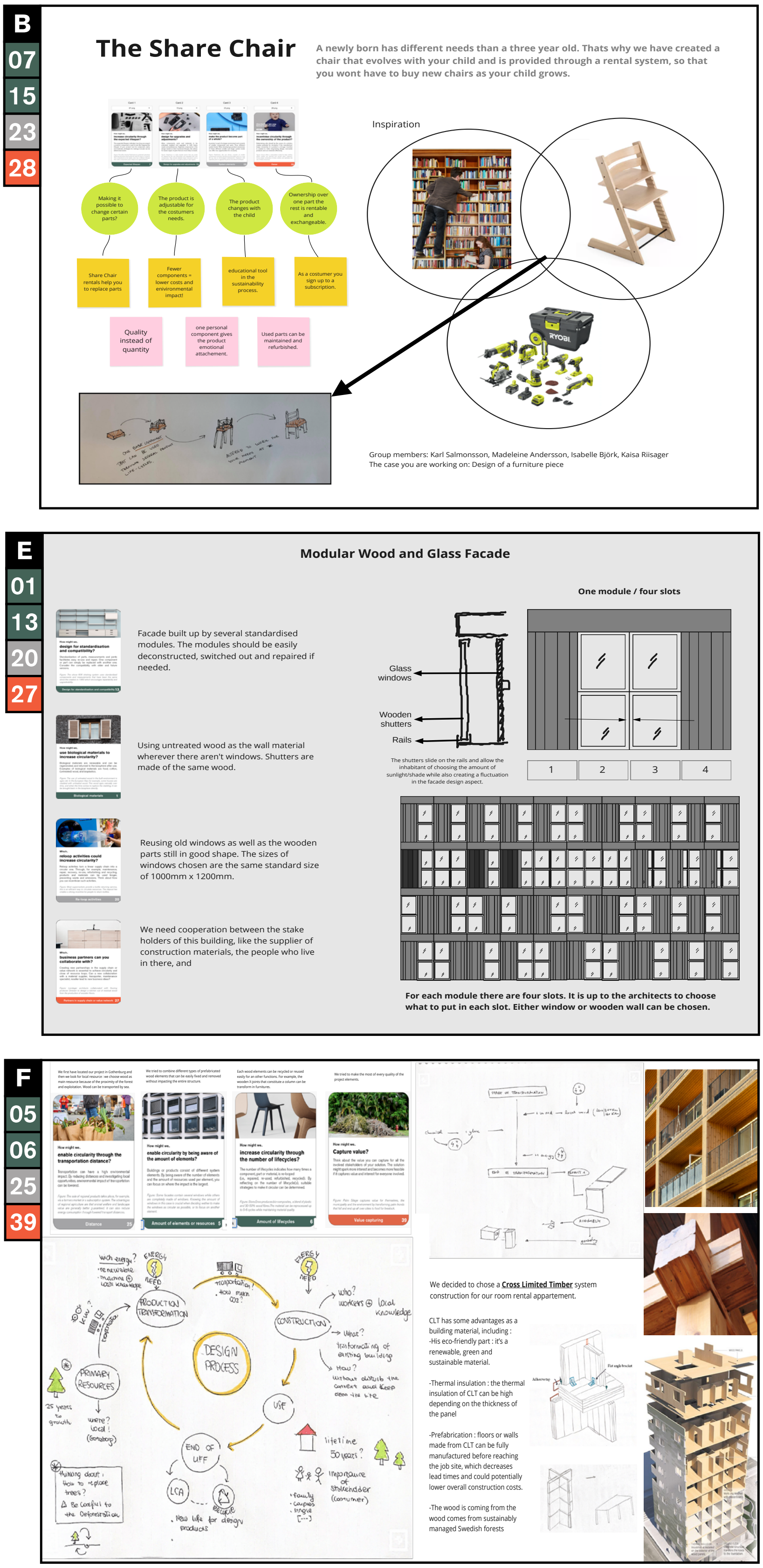


*Figure 19.* Selection of workshop results extracted from workshop Miro boards. Cases: (B) Design of a furniture piece, (E) Design of a façade, (F) Design of an apartment building. Numbers represent selected cards (see paper E for an overview of the cards), the colours (green, grey and orange) distinguish the technical, industrial and business model, respectively.

disassembly, the use of biological materials, and the collaboration between partners in supply chains and value networks (see appended paper E for details on the frequency of selected cards).

Although the results suggested that participants found specific cards particularly appealing or interesting, 51% of the participants indicated that cards were selected because they suited the context of the case while only 21% mentioned the selection was because the cards seemed interesting or fun. The results also showed that specific cards were selected considerably more often (or less) for the different cases, suggesting that some strategies were seen as more or less suitable depending on the context and scale of the design assignment.

The analysis of 75 Miro boards with design outputs revealed that many groups followed similar approaches, despite the lack of clear instructions on what the workshop outcomes should look like. The students often included diagrams and flowcharts describing the principles and core ideas extracted from each card, and a final concept sketch of the proposed design solution with clarifications of how the extracted principles were integrated. Figure 19 shows a selection of segments from the Miro boards, showing the breadth of proposed solutions ranging from tangible design artefacts (e.g., product, construction), business models and service solutions, and system diagrams showing the proposed lifecycle or value chain (with corresponding steps and activities) of the imagined solution.

## 4.4 Cross-study findings

### 4.4.1 The practical implications of circular design

Multiple studies were conducted that examined the practical implications of designing for a CE, mainly through inquiring design practitioners directly. Papers A and B (and to some extent paper D) investigated how design practitioners currently interpret the CE concept and how circular design affects the process, practice, and roles of design practitioners. Furthermore, these studies also looked at factors that currently support and hinder circular design in practice. While the findings within this theme are primarily based on papers in study 1, study 3 was (chronologically) the first inquiry with design practitioners through a focus group discussion and interactive survey. Study 3 provided some early relevant insights that were later again identified and expanded on in papers A and B:

- Designing for a CE is as much a business challenge as a technical challenge; designers need to understand business aspects and require business knowledge to understand the economic and business implications of a circular design approach, and to communicate this to clients.

- Advancing circular design is ultimately dependent on the willingness of clients, and clients are currently hesitant towards circular solutions as they often imply structural changes to the current processes, capabilities, systems, and business models of companies.

- Designing for a CE requires designers to engage even further with the lifecycle and EoL scenarios of products, and to enable this there is a need to collaborate more with relevant experts and actors both upstream and downstream in the value chain.

- In the early conceptual stages of the design process, it remains difficult to assess and anticipate the effects of design choices on the (potential for) circularity of a given product because the standard and most common assessment methods available (i.e., LCA) require a high level of technical specification and data which is often not available.

The findings of paper A indicated how the CE discourse has affected the practice and role of industrial designers and architects, providing a better understanding of the challenges of circular design and how challenges are addressed. It is apparent that designing for a CE on the one hand expands the scope of already existent challenges and roles in the design process (e.g., related to connecting actors and addressing the design of whole systems and value chains), and on the other hand also induces new challenges and roles (e.g., designing for circular business models, handling the logistics around reuse of materials on a building level).

While all three studies indicated the importance of collaboration in the context of circular design, paper B provided a more nuanced understanding by showing that collaboration is neither seen as one of the major challenges of designing for a CE nor an area where designers seem to lack knowledge or competences, instead the results indicated that practitioners play an important role in connecting actors and actively engage in new networks and collaborations to promote circularity. The survey results of study B indicated that architects, compared to industrial designers, are more actively pursuing stakeholder involvement and co-creation in projects that address circularity. Study A and B exhibited similar results regarding the differences between industrial designers and architects in their design approach towards a CE, reinforcing the finding that architects (currently) emphasise closing resource loops (reuse of materials on a building level), while industrial designers emphasise slowing resource loops (product lifetime extension strategies and circular business models). An observation that can be made when comparing the findings of the different studies is that the current efforts and trends regarding circular design in practice also seemed to be echoed in the interpretation and definition of what circular design constitutes within respective design disciplines. For instance, the survey in paper E found that architectural students (based on around 300 responses) associate circular design primarily with the reuse of waste and secondary raw materials, while circular design in the built environment also refers to other strategies and approaches (e.g., design for longevity and disassembly).

The survey study (paper B) also provided a more nuanced perspective on some of the earlier findings from the interviews (paper A). For instance, current regulations and policies as well as the predominant structures and conditions in the design industry (e.g., related to project contracts) were foremost seen as obstacles by architects, but not to the same degree by industrial designers. Lastly, papers A and B yielded similar findings regarding the expressed need for deeper material knowledge to design for a CE (regarding their impact, ageing, and availability) and for better ways of assessing the environmental and economic impacts of design proposals attuned to the workflow and design process. While these findings were from the perspective of design practitioners, paper E provided similar findings but then from the perspective of architectural students.

### 4.4.2 The role of co-creation in design for a circular economy

An important aim of this thesis was to provide a better understanding of stakeholder collaboration and co-creation in the context of design for a CE. The results of the interviews in Study 1, based on real cases experienced by design practitioners, illustrated that the scale, complexity, and importance of collaboration increases in design projects that focus on slowing and closing resource loops. Actors across value chains need to go beyond conventional vendor-client relationships and develop their collaborations to enable circular solutions, and the findings show how designers can have a pivotal role in connecting actors and facilitating collaboration to enable innovative solutions towards a CE.

The survey study in study 1 provided a more nuanced perspective by showing that stakeholder collaboration is not perceived as the most crucial challenge of circular design; many design practitioners already actively partake in new networks, research projects, and collaborations (e.g., material and component suppliers) to gather knowledge and advance circular design. While study 1 provided an initial understanding of collaboration and co-creation in the context of a CE from the perspective of designers, they provided limited insights from the perspectives of other actors involved in the design process, and how diverse actors across the value chain interact in the process of co-creating solutions for a CE. Study 2 complemented this by providing a first-hand and longitudinal perspective on the process of co-creation in the context of COI, and showed how collaborative prototyping can help foster collaboration towards circular supply chains. The study indicated that co-creation in the form of workshops is particularly impactful during the early stages of COI to help guide projects, enable shared learning, build confidence and commitment amongst stakeholders, and support the development of solutions tailored to the demands of the parties involved.

While the findings of study 1 indicated that design practitioners consider it an opportunity and responsibility to engage and educate clients about the CE concept, they also acknowledged that the possibilities to do this are limited when clients lack willingness and commitment towards sustainability and circularity. In this regard, study 2 indicated that it can take substantial time for companies to develop their understanding and awareness of the CE concept, and embrace the shift from a linear to a value creation logic as a CBM will nearly always challenge the existing organisational, technological, and industrial structures of a company.

Yet, study 2 also indicated that as stakeholders increasingly understand CE as a systemic and industry-wide challenge that requires comprehensive solutions (e.g., developed together with other value chain actors or competitors), they can develop an increased willingness for horizontal and vertical value chain collaboration. An inherent challenge with this task is that the CE is an umbrella concept which is interpreted differently by different actors (between designers, clients, manufacturers, and other stakeholders) which makes it difficult to operationalise the concept effectively and comprehensively. Hence, the CfC was found to have a supportive function in multi-stakeholder settings and workshops, as it allowed for the articulation and negotiation of diverse perspectives towards CE strategies. The CfC was initially developed as a generative toolkit to co-create holistic circular design solutions and findings from different workshops with practitioners working in the construction industry and architecture students indicated that the toolkit was found helpful in broadening the understanding of the CE concept and developing ideas based on different circular strategies (see figure 20).

Yet, the analysis of 156 written comments resulting from study 3 revealed that participants appreciated the tool mostly for facilitating discussions on definitions and design strategies for a CE and for understanding and aligning each other's perspectives and broadening the solution space. Over the years, 3 different versions of the tool were used in 7 different workshops by 623 people (see Table 1 in section 3.2.3). Similar findings from different workshops indicated that the tool was found supportive in generating holistic ideas by considering the technical, business, and industrial context, yet something that was found to be lacking was an additional step where participants reflected on why a certain idea was circular and (qualitatively, preliminarily) assessed the potential for circularity of a developed idea.

The different iterations and versions of the CfC toolkit also came with different learnings. In the first version, the printed cards represented different strategies with simple illustrations that depicted the strategies and were laid out on a physical map. In the second version, a web tool was developed featuring a button that randomised combinations of cards to promote unexpected and surprising directions, strategies were phrased as questions and pictures of real cases were included to make the cards more tangible and actionable, and the map was omitted to reduce cognitive load. In the final version, different workshop stages were included in which the participants purposefully selected cards, eliminating the element of surprise but instead allowing for a selection of cards considered suitable in a certain context by the user.

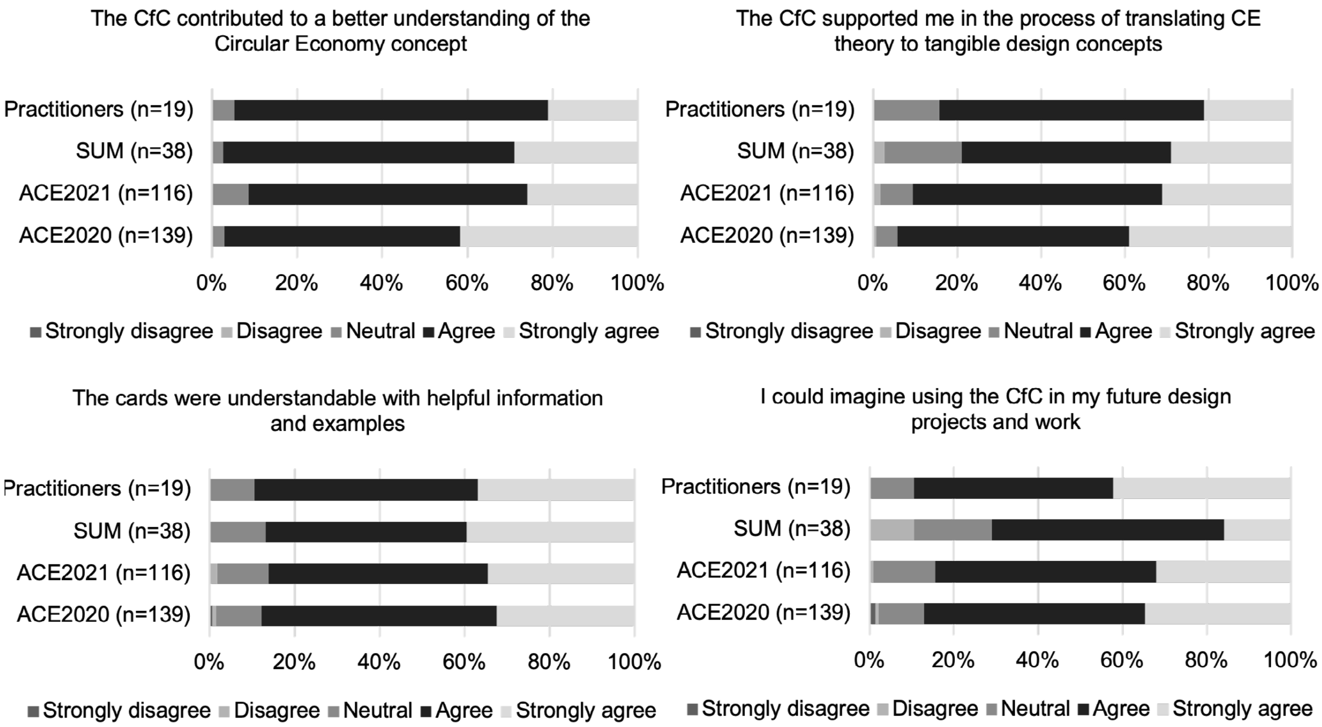


*Figure 20.* Results of post workshop surveys regarding the perceived usefulness of the CfC tool according to master students architecture at Chalmers University of Technology (ACE2020, ACE2021), master students architecture at Delft University of Technology (SUM), and practitioners working in the construction industry.

While the role of the facilitator was important for the coordination and execution of the workshop with the CfC, a workshop manual was developed alongside the tool that allowed participants to go through the workshop stepwise with limited support needed from the facilitator (see appendix B). The CfC was initially developed in the context of the CIK project to support the co-creation workshops, and the project stakeholders appreciated that the design researchers compiled a list of design strategies and guidelines that were relevant for the context of building components such as the kitchen, as it made CE strategies tangible and actionable and directly supported the stakeholders in the project to broaden and structure their creative thinking.

# 5. Discussion

This thesis explored how the CE concept is implemented in design practice and how circular design can be promoted in practice. The thesis particularly investigated the role of co-creation in supporting design for a CE, and how co-creation can be supported during CE-focused design and innovation processes. This chapter discusses the findings of this thesis in relation to previous research and the research questions. Moreover, the limitations of the thesis are also discussed.

## 5.1 Exploring current perspectives on circular design

*RQ1: How is the concept of a circular economy currently interpreted and operationalised within design practice?*

### 5.1.1 Circular design in practice across architecture and industrial design

The results of this thesis indicate that the CE represents several new, yet not entirely unique challenges for designers. A distinct attribute of circular design is the underlying principle of a closed-loop economy in which resources are kept at their highest utility and value, thus striving to resolve issues related to waste generation and resource efficiency rather than mitigate them (den Hollander et al., 2017). This challenges designers to ‘zoom out’ further and design purposefully with a deeper awareness of the spatiotemporal parameters of products and materials (e.g., anticipating how materials change over time, and issues of reverse logistics). Circularity is the property of a system and not of an individual artefact (Konietzko et al., 2020a), therefore the design process should take into account other interrelated components of the circular system (e.g., business models, value network configurations) that are ultimately vital to effectively extend the lifespan and value of products and materials.

Study 1 indicated that design practitioners emphasise the necessity of a systems-oriented approach to the CE, and 40% of the surveyed industrial designers and architects saw systems thinking as a concrete challenge of circular design. Previous studies have highlighted the importance of systems thinking in sustainable design (Blizzard and Klotz 2012; Charnley, Lemon, and Evans 2011; Gaziulusoy and Brezet 2015; Joore and Brezet 2015; Lambrechts et al. 2019; E. Manzini and Vezzoli 2003; Vezzoli et al. 2015) and the context of sustainable PSS solutions (Brezet, Diehl, and

Silvester 2001; Tukker 2004). This emphasis has also been extended to circular design (Bocken et al., 2016; De los Rios et al., 2017; Moreno et al., 2016; Sumter et al., 2021) and some extent in the context of a circular built environment (Joensuu et al., 2020; Ness and Xing, 2017). Despite the articulated importance of systems design in study 1, it remained unclear how such an approach is fostered and whether it is supported by specific tools or methods. In this regard, Charnley et al. (2011) notes that designers have received limited guidance on how to effectively integrate whole systems design within increasingly complex design processes.

The findings of study 1 indicated that circular design has gained substantial traction amongst architects and industrial designers in the Netherlands and Sweden; 63% of the survey participants had experience with CE-focused projects and the majority reported changes in their organisations to adapt to a CE. The findings also suggest that architects and industrial designers have different interpretations of circular design and different foci in operationalising the CE concept. The architects frequently mentioned and incorporated strategies related to the reuse of waste and secondary raw materials for the design of new buildings and structures, and finding ways to avoid new construction (e.g., through renovation). Both architectural students and practitioners appeared to associate circular design primarily and sometimes exclusively with these strategies. Strategies for designing buildings and building components so they can be easily disassembled (DfD) and reused in the future, and so they are more easily maintained and repaired (e.g., modular design) were less discussed and implemented. A possible explanation for this is that the reuse of building materials for new construction is currently a viable strategy with direct environmental benefits (in terms of reducing carbon footprints and resource consumption), while the long-term effectiveness of strategies such as design for disassembly and new digital technologies such as material passports remain somewhat uncertain and unproven at scale. The focus on material reuse as a strategy has consequences for the architectural design process; greater flexibility is required due to the uncertainty of what materials and components are available, shifting design processes from goal-oriented (the design is driven by predefined goals) to means-oriented (the design is driven by available means); (De Jong and Van der Voordt 2002). Various scholars have discussed the implications of these developments for the architectural practice for example related to the role and design process of architects (Galle et al., 2018; Kanters, 2020; Kozminska, 2019) and developed supportive interventions including dedicated design frameworks and methods (Cambier, 2022).

Industrial designers on the other hand have a stronger focus on incorporating strategies that facilitate lifetime extension and circular business models, such as DfD, modular design, and PSS solutions. While circular and servitized business models appear to have received greater attention in the context of product design, PSS solutions may hold significant potential within architecture to facilitate the efficient use of buildings (e.g., sharing economy principles) and maintenance and service models, which could help decrease resource consumption and the growth of the building stock (Fargnoli et al., 2019; Joensuu et al., 2020). Kanters (2020) explained that the increased complexity of the building scale in regards to the number of stakeholders, and issues of ownership, could be a possible reason that hinders further adoption. While designing for longevity is commonly understood (amongst designers) as sustainable and 'good' design practice, it was observed that certain design strategies appeared strongly associated with circular design, such as design for disassembly, increasing the use of renewable and secondary raw materials, and circular services and business models. Strategies such as design for disassembly and circular services and business models are key for circular product design (Bocken et al., 2016) and may therefore strongly connect to current efforts in design practice and the notion of circular design.

Despite the growing attention to circular design from various organisations (e.g., NGOs, trade unions, consultancies, manufacturers), a coherent conceptualisation and theoretical foundation for circular design is largely missing. This is perhaps not surprising; circular design as a concept has been driven mostly by practitioners in business environments, and the CE concept itself is ill-defined and broadly interpreted (Kirchherr et al., 2023, 2017). The R-imperatives (e.g., reduce, reuse, recycle) form a common CE vernacular for designers but the findings of this thesis illustrated how these terms are also used interchangeably and in fundamentally different ways. For example, reuse for architects primarily relates to reusing building materials and components for the design of new structures, while reuse for industrial designers mostly refers to the reuse of products by other consumers in future use cycles. As pointed out by Reike, Vermeulen and Witjes (2018), there is a considerable conceptual ambiguity across the R frameworks and a shared understanding of key notions amongst practitioners is critical for a successful implementation of a CE as ‘different languages and professional jargon are used by stakeholders possessing different underlying paradigms’ (p.254).

A challenge for umbrella concepts such as the CE is to, after the initial excitement period (in which the concept promisingly and seemingly links previously unconnected concepts), ensure theoretical cohesion and avoid construct collapse (Blomsma and Brennan, 2017). In the case of circular design as a concept and guiding framework, there may be a need to more clearly define what circular design constitutes and provide a robust theoretical foundation, so that practical efforts align with CE principles and contribute to sustainable development in the best way. To foster holistic and interdisciplinary approaches towards circular design, the further development of common and comprehensive guiding principles for circular design could be useful to synergise design perspectives and promote alignment, knowledge exchange, and collaboration.

### 5.1.2 The intersection of architecture and industrial design

Investigating CE practices within both industrial design and architecture, despite the differences between these two distinct fields, was considered helpful for the scope of the research (and design) work carried out during this thesis and contributed to the richness of the findings. The present research found several intersections between industrial design and architecture, where further synergy and cross-pollination could contribute to the overall advancement of circular design. On the one hand, industrial designers can learn from architectural approaches towards understanding and working with locality (in terms of material availability, infrastructure, industrial capacity) and spatial challenges regarding the (reverse) logistics of products and components and material flows, especially considering the European ambitions of reducing the dependency of global manufacturing value chains and moving towards more resilient locally based production systems (European Commission, 2020c). On the other hand, the discipline of industrial design (particularly strategic and service design) is well-equipped to address important 'user-centred' challenges in the context of a circular built environment, for example concerning the servitisation and digitalisation of building components and the successful integration of PSS solutions to enable better management and maintenance of buildings (Fargnoli et al., 2019).

Pomponi and Moncaster (2017) argued how buildings are unique, complex, long-lived, and ever-transforming artefacts once assembled, therefore solutions that are suitable for manufactured products are unlikely to be applicable for buildings of which the manufacturing and useful lifespan extends over a significantly longer period. Indeed, the effectiveness and compatibility of any design strategy will depend on the characteristics of a given artefact, context, and business constraints (Bakker et al., 2014). Nevertheless, it is vital that designers develop a holistic understanding of potential design strategies that contribute to a CE, and think and act according to the entire spectrum of resource value retention strategies. In this regard, the taxonomy of slowing, closing, and narrowing resource loops with corresponding design and business model strategies presented by (Bocken et al., 2016) can be a helpful aid and overview for designers. Moreno (2016) further elaborated on this work and proposed a conceptual framework for circular design, considering a broader scope of DfX (Design for Excellence) strategies and suggesting business model archetypes for different resource flows. These frameworks however have limited applicability for architects, and so far, there are only a few frameworks that provide a coherent overview of design strategies in the context of the built environment. One example of a framework for architects which lists design strategies in a hierarchical taxonomy is the Circular Buildings Toolkit (Ellen MacArthur Foundation and ARUP, 2022). As the CE transition is a challenge that spans across scales and disciplinary boundaries, it will not be surprising to see initiatives deploying closer collaborations and synergies between design disciplines (e.g., architects, industrial designers, service designers, strategic designers), such as the 'New European Bauhaus' that the EU envisions to help Europe move toward a CE (European Commission, 2020d).

### 5.1.3 The effects of the circular economy on the practice of design

Study 1 indicated that in the context of the CE, designers are increasingly questioning the linear logic and transactional nature of design projects and contracts in consultancy settings. Some practitioners pursue alternative revenue models and long-term client relationships to become more involved throughout the entire lifecycle of designed artefacts rather than perceiving design projects as temporary endeavours that are finalized and handed over. Particularly architects agreed that the CE requires different models for rewarding design work (60% of the surveyed architects in paper B), which could relate to Galle et al. (2015) who pointed out that in the value chain of construction, the involvement of architectural designers only represents a short period relative to the long-term impact of their choices, while it is precisely the architect who can help ensure long-term value through lifecycle thinking and the well-considered management of buildings.

The findings of study 1 revealed that designing for a CE has significant implications for design projects in agencies. It expands the scope, duration, and costs of design projects and drives the integration of additional knowledge (e.g., of materials, circular business model innovation, biology, value/supply chain management) and requires the involvement of more stakeholders from the start of the design process than in a traditional linear economy model. The results show that agencies address CE-related knowledge gaps by acquiring new knowledge, collaborating with external experts in the design process, engaging in dedicated CE networks, and assigning dedicated CE teams and experts.

Aside from grasping the breadth of circular design strategies that can be utilised, a common challenge for designers and architects remains to decide what design strategy is the most effective and feasible in different contexts, and where to focus their efforts in terms of promoting circularity and resource efficiency. To cope with these challenges, the thesis found that both architects and industrial designers expressed a strong need for better material knowledge, assessment methods, and case studies to make better-informed decisions at the design stage. Some scholars have argued design efforts should (currently) primarily focus on reducing the rate at which resources are required (i.e., material and energy efficiency)(Allwood et al., 2011), yet Bocken et al. (2016) pointed out that resource efficiency alone does not address the rate at which products are sold and consumed (thus lifetime extension is also instrumental). While it is a case-by-case challenge to define suitable design strategies according to the optimal intended lifespan for a given artefact (Bakker et al., 2014), it remains vital that further research equips designers with accessible information and design guidelines based upon case-based evidence (Møller et al., 2023; van Stijn et al., 2022a).

It was also observed that design practitioners who are actively engaged with the CE concept frequently undertake efforts to develop (and customise existing) tools and methods to address challenges related to estimating the impacts of material and design choices in early design phases, and engage with issues such as business model innovation. While fitting tools and techniques to specific problem areas can be considered a natural ability of designers (Laursen and Haase, 2019), it could also reflect that existing circular design support tools and methods are not sufficient or readily available (Cambier et al., 2020; Kanters, 2020). Furthermore, Faludi et al. (2020) pointed out that existing sustainable design tools may be sufficient, but they are insufficiently published, adopted, required by regulations, and integrated into the social norms of practice.

## 5.2 Factors supporting and hindering circular design in practice

*RQ2: What factors are currently supporting or hindering circular design in practice?*

It is apparent that for both architects and industrial designers, the most prevalent challenges for circular design currently can be considered mostly beyond the direct control of designers and primarily relate to business aspects and financial feasibility, the limited willingness of companies to invest in circular solutions, and current regulations and policies. These findings are in line with other qualitative studies on challenges faced by design practitioners when engaging with circular design (Cambier et al., 2020; Münster et al., 2022), which also highlighted that the designers' influence to incorporate circular design is ultimate dependant on willing clients, market economics, and supportive standards and regulations. Clients are considered hesitant due to the associated financial risks, higher costs of technical solutions and the perceived constraints resulting from the current linear system. This is consistent with the general CE barriers identified in previous studies related to hesitant company cultures and a limited willingness to change, a limited willingness to collaborate in the value chain, the existing linear system and attitudes to and knowledge of the CE (Kanters, 2020; Kirchherr et al., 2018). It should be noted that regulations and policies primarily appeared as a major obstacle for architects, which can be explained by the focus on the reuse of building materials and components, a design strategy faced by constraints as building components are governed by strict regulations (Condotta and Zatta, 2021; Nußholz et al., 2020).

One of the major prevalent challenges which appear largely within the direct control of designers is estimating environmental impacts during the design process. Assessing the environmental effects of material and design choices at the initial stages of the design process, when limited information and technical specifications are available, appears as a persistent challenge for design practitioners. Challenges related to consumption behaviour and human factors were more frequently reported by industrial designers, and various studies have emphasised the crucial role of people's behaviour in the design and realisation of circular value propositions (Lofthouse and Prendeville, 2018; Selvefors et al., 2019; Wastling et al., 2018). Ultimately, the success of circular design strategies and the widespread adoption of circular business models is also dependent on the engagement and acceptance of people towards circular offerings (Gullstrand Edbring et al., 2016; Tunn et al., 2019; van Weelden et al., 2016). In the context of the built environment, there are also reasons to further investigate people's acceptance towards reused and repurposed building materials and components as these can influence the success of reuse strategies, as illustrated in paper A with an example where tenants were unreceptive towards flooring material reused as wall cladding. So far, there have been few investigations on the perception and acceptance of people towards reused and repurposed materials aside from (Sieffert et al., 2014).

The findings also indicated that practitioners find it difficult to distinguish and verify 'circular' material alternatives concerning renewable and low-impact materials, and are also faced with confusion and misconceptions from the perspective of clients and consumers. Negative associations towards non-renewable materials such as metals and polymers and a positive bias towards renewable materials such as wood may in some cases constrain designers from developing the preferred circular solution, as the choice of such non-renewable materials might be justifiable from the perspective of circularity and the environmental impact over multiple lifecycles. Münster et al. (2022) also noted this hesitant behaviour amongst retail designers when information is lacking to reliably verify sustainable materials and products.

This thesis indicates that practitioners respond to the aforementioned challenges by acquiring new knowledge and expanding their competencies, actively developing and customising support design tools and methods for the context of the CE, and engaging in new collaborations to complement the expertise and dedicated networks that promote circular design. Previous studies have elaborated on the knowledge, skills, and competencies designers must develop for design in a CE (Andrews, 2015; De los Rios et al., 2017; Sumter et al., 2021, 2019), and the results of this thesis complements with insights and a more nuanced understanding of knowledge needs from the perspective of design practitioners, and how they go about acquiring necessary knowledge and expertise. The results revealed that the sporadic need for CE-related knowledge is often addressed through collaboration with experts in specific domains, while repetitive and structural knowledge gaps are addressed through dedicated projects, assigning experts, and the development of appropriate tools and guidelines.

Practitioners particularly pointed out the need for material knowledge, consistent with (De los Rios et al., 2017; Kanters, 2020; Lilley et al., 2019) who emphasised that designing products and buildings according to the principles of slowing and closing resource loops require a deeper understanding of materials (e.g., regarding their impact, availability, durability, wear, and tear). Overall, the results indicate that CE necessitates a holistic design approach that requires designers and architects to further develop interdisciplinary knowledge about business thinking, stakeholder management, materials, and environmental impact assessment. Some of these competencies (e.g., regarding business and managerial implications) are already well-established in the domain of strategic and service design, and some design agencies specialise in 'business design' as a service.

The results of this thesis indicate that designing for a CE inherently and simultaneously entails technical design challenges and business challenges, and to move from a linear to a CE, "design strategies and business model strategies will need to go hand in hand" (Bocken et al., 2016). Ultimately, innovation for a CE will demand designers to find promising synergies between the technical, business, environmental, and societal interventions which are more likely to result from holistic and integral design approaches. Meyer and Norman (2020) argued that design education is struggling to keep up with the current global and societal challenges, and that a broader skill set and interdisciplinary knowledge are required to help designers become effective leaders and collaborators, and to be influential in high-level positions. In line with this, Charnley et al. (2011) argued that systemic challenges such as the CE require a balance between discipline-specific and trans-disciplinary skills. Sumter et al. (2021) provided a comprehensive overview of the CE key competencies for design, which could be useful for design education and serve as a 'template' for fostering circular design capacity in design teams. Rios et al. (2017) added a different perspective by arguing specialists are best at addressing specific design challenges, and suggested different CE 'design personas', such as the 'product-service designer' and the 'retrofitting designer'.

To date, a rich variety of circular design guides, methods, and tools have been made available by various actors (e.g., NGOs, trade unions, consultancies, and manufacturers). As discussed in section 5.1.3 many survey participants in study 1 pointed out to already use tools and methods for circular design, yet many participants also highlighted the need for more tools and methods (especially environmental and economic assessment methods) and undertake efforts to develop their own design methods and tools to address design challenges related to the CE. This could relate to (Cambier et al., 2020), who noted the oversupply of tools illustrating the basic principles of circular design and urged for addressing the actual needs of practitioners and proper guidance on the use of design support tools. Furthermore, Kanters (2020) pointed out the need for standardised LCA methods within the industry that are attuned to the workflow of designers. Another factor supporting circular design is the development of new digital technologies, IoT, and data-driven solutions (e.g., material passports, digital twins), as these can help bridge the gaps in connecting and closing resource flows (Alcayaga et al., 2019; Ingemarsdotter et al., 2019). Debacker et al. (2017) described how material passports can provide information about the present use, recovery and reuse of materials and components and inform designers and decision-makers about the technical and spatial reversibility of design solutions. As physical artefacts increasingly become 'living' assets that can be embedded with digital information (e.g., through RFID tags), they can also support architects and industrial designers in better understanding and optimising product and building lifecycles.

The findings of study 1 indicated that many design practitioners engage in a variety of regional, industrial, and international networks promoting the circular design of products and the built environment, and these initiatives appear as fruitful grounds for knowledge exchange, collaboration, and addressing systemic challenges for circular design. Moreover, there are examples of various EU countries that have developed governmentally supported programs to educate and stimulate designers and manufacturers in designing circular products, services, and business models (e.g., Circo in the Netherlands, and Danish Design Center in Denmark). To successfully and comprehensively equip designers with relevant knowledge and guiding frameworks and tools for circular design, coordinated efforts between governments, practitioners, and researchers are needed – a recommendation also pointed out by (Ahmad et al., 2018) in the context of eco-design. This can be achieved for instance through openly accessible platforms that collect industry needs and circular design methods and tools, sortable by specific characteristics and enhanced by decision support on when what intervention is appropriate (Faludi et al., 2020).

## 5.3 Co-creation and the role of designers

*RQ3: What is the role of co-creation in supporting design for a circular economy?*

The results of the thesis indicate that actively engaging and involving actors across the entire supply chain early in the design phase, and deploying a co-creative approach (e.g., through workshops) in which each actor can contribute to solutions from their perspective and expertise, is crucial to enable joint learning, an ecosystem perspective (Konietzko et al., 2020a), broaden the solution space, and establish a feeling of commitment and shared ownership. This is particularly important in the built environment, where silo thinking and a lack of collaborative approaches are major challenges (Adams et al., 2017). Study 2, which addressed the development of the circular kitchen, made apparent that the primary challenges of designing solutions for a CE did not relate to the actual design and construction of the kitchen, or any technological barriers or constraints. The longitudinal findings show that engaging the supply chain in a circular innovation trajectory can be complicated from a process perspective; involving supply chain actors early is difficult when it is not sure what capabilities and stakeholders are needed to realise a circular value proposition. Moreover, participants might not all see opportunities for (shared) value creation and display diverse levels of participation and commitment throughout the process. Related to this, Blomsma et al. (2019b) highlighted that co-design processes in COI should always allow for the inclusion of new stakeholders to complement with necessary knowledge and capabilities, as iterations towards a CE value chain might be needed before the full set of stakeholders and possibilities for shared value creation are clear.

Consistent with Guldmann and Huulgaard (2020), the encountered challenges in study 2 mainly related to the radical shift companies need to go through when shifting from a linear to a circular value creation logic, the involvement of the supply chain and collaboration between project stakeholders, and deploying a concurrent approach towards the development of a circular product, business model, and supply chain. The challenges are also in line with other studies that report that the major barriers for a CE are not of a technological nature but rather are cultural and organisational such as hesitant company cultures and limited willingness to collaborate in value chains (Kirchherr et al., 2018), and limited support in the supply and demand networks (Rizos et al., 2016).

The findings of study 1 showed how some design practitioners act as 'connectors' in the context of the CE, by facilitating connections and collaborative spaces between supply chain actors to enable circular solutions. In some of the discussed cases, new connections that were initiated between actors and the facilitated collaborative space were vital elements in the success of those design projects. Previous research has discussed the role of designers as connectors (Manzini, 2009) who can facilitate strategic dialogues between actors (Meroni, 2008), establish future visions and act as agents of change (Banerjee, 2008). Kanters (2020) argued that architects can play a central role in the CE transition by linking actors but would require additional knowledge (e.g., leadership qualities), and (Münster et al., 2022) pointed out that the central role of design in a systemic and collaborative approach towards a CE needs to be articulated, practised, and broadcasted. Furthermore, as shown in Study 2, the careful planning of activities during design processes that foster supply chain partnerships and collaborations can be crucial, and the resulting networks and partnerships can be valuable outcomes of the design process. Therefore, it is vital to acknowledge CE collaboration and the value network configuration as integral parameters of designing for a CE, as they may ultimately be crucial for the success of efforts in practice. Pedersen and Clausen (2019) investigated the process of co-design for a CE and emphasised that the key to success is not solely the design of material artefacts but rather the design of the stakeholder network and relationships.

The results of study 1 also indicated that some agencies seemed to specialise in facilitating collaborative platforms and coordinating industry-level innovation projects by deploying co-design methods. In addition, nearly half of the surveyed design practitioners have engaged in new networks and collaborations to adapt to the CE, and the majority of architects reported involving a wider network of value chain stakeholders and deploying value chain co-creation in projects that focus on CE. In this regard, Sumter et al. (2020, 2021) defined 'circular economy collaboration' as an important competence for industrial designers, and found that this was one of the most frequently utilised competencies based on a survey with 128 designers working on CE projects. The importance of interdisciplinary collaboration and co-creation in tackling global and societal challenges, and the evolving role of designers in society, appear also reflected in the emergence of other design frameworks within the last decade such as transitions design (Irwin, 2015), relational design (Nielsen and Bjerck, 2022), and design for social systems (Both, 2018). The relevance and intersections of these frameworks for the context of the CE remain to be further explored and investigated.

## 5.4 Supporting co-creation as a part of circular design

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*RQ4: How can co-creation as a part of design for a circular economy be further supported?*

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Within the context of design and business practice, co-creation can be seen as an approach that is characterised by facilitated participation in orchestrated multi-stakeholder environments, in the form of workshops and self-organising modes of engagement (Jones, 2018). The findings of this thesis suggest that designers can have an impactful role in the CE transition by facilitating interdisciplinary collaboration and co-creation in the development of new products, buildings, and services with potential for circularity. Such approaches are important in the transition to a CE; many companies who engage in conventional vendor-client relationships are not used to the type of innovative partnerships that are necessary for the realisation of circular systems (Brown et al., 2020). The findings of this thesis provide deeper insights about the supportive role of co-creation in the context of design and innovation for a CE, and the role of designers as facilitators for stakeholder co-creation in a CE.

The CfC showed potential as a generative toolkit that describes a participatory design language (Sanders, 1999) and can stage discussions on different circular strategies, support ideation, and align perspectives in multi-disciplinary and multi-stakeholder contexts. The CfC was developed to support the design of circular building components (van Stijn and Gruis, 2019) and encourage systems thinking by distinguishing the relevant interrelated parameters of the (technical) design strategy, business model and industrial model (relating to value chain interaction and networks). Analogue toolkits such as card decks and board games have been found supportive of collaborative ideation as they provide a shared language and goal, and facilitate collaborative experimentation and the reification of abstract concepts. Moreover, Roy and Warren (2019) noted the important strength of cards as a "physical artefact that people can interact with" and their ability to provide a common basis for understanding and communication in a team. The results indicated that entirely digital tools (digital cards as web-tool) also functioned satisfactorily for collaborative ideation in digital and on-site workshops and provided some additional benefits such as more possibilities for rich explanations, easier distribution, and a more convenient format for iterations and testing of the tool. It should also be noted that the CfC is one tool developed for a certain context; other card-based circular design tools resulting from scholarly research also exist and focus for example on user-centred circular design (Rexfelt and Selvefors, 2021), innovation ecosystems (Konietzko et al., 2020b), and product longevity in fashion (Hasling and Ræbild, 2017). The question of who will take on the role of 'connector' and facilitator in COI likely yields multiple answers and perspectives. Existing design consultancies expand their scope and offer dedicated services (e.g., see IDEO's CoLab), new types of consultants or specialist designers might appear (De los

Rios et al., 2017), and it might generally become a more central task for designers and architects (Kanters, 2020; Münster et al., 2022). Nevertheless, many designers will likely face challenges in practice that require more extensive involvement and collaboration of stakeholders across the entire supply chain, and could benefit from toolkits such as the CfC, and other dedicated guiding frameworks and prescriptive methods for stakeholder co-creation in CE-oriented design projects.

Overall, the landscape of tools that support co-creation is characterised by tools that are made available without research behind them and supplied evidence on tool efficacy, and research on tools that are not made available (Peters et al., 2020). Some prescriptive frameworks and methods that have been developed by scholars that potentially support co-creation in innovation towards a CE, range from process models (Blomsma et al., 2019b; Bocken et al., 2018; Brown et al., 2021b; Leising et al., 2018) to design thinking frameworks that provide practical guidance and details on iterative phases, activities, and proposed timelines (Blomsma et al., 2020; Brown et al., 2021a; Guldmann et al., 2019; Santa-Maria et al., 2022a). While most of these frameworks display a somewhat linear process, study 2 illustrated that it is important to incorporate iterative cycles due to circumstantial factors (e.g., stakeholders leaving or entering), and different participants might need tailored approaches and entry points based on their CE maturity level. Moreover, not all frameworks provide practical guidance in terms of how the frameworks can be operationalised in design and business practice.

To foster stakeholder co-creation in the design of circular products and services it is key to further investigate and assess to what extent the aforementioned frameworks and other co-creation approaches and techniques such as the ones described in (Sanders and Stappers, 2012) can be further incorporated within the design process and practice of architects and designers. Since the success of co-creation efforts relies on more than just the proficient use of frameworks, it is also relevant to further assess other factors such as how to enhance collaborative efficacy in design co-creation (i.e., the collective belief of a group in achieving effective collaboration and desired outcomes), the role of the facilitator, and the influence of offsite or "neutral" locations for design workshops (Jones, 2018). Finally, designers and practitioners need to be equipped with suitable frameworks and approaches for co-creation through coordinated efforts, and need to be equipped with the knowledge and competencies to facilitate and engage collaboration across value networks (Sumter et al., 2021).

## 5.5 Limitations

This section provides a summary of the limitations of the overall thesis, while section 3.3 provides a more detailed explanation of the implications and limitations of the chosen methodology.

Firstly, it should be noted that due to the exploratory and largely inductive approach of the research, the thesis made limited use of extant theoretical frameworks that could have enriched and helped interpret the empirical evidence. The thesis to a great extent examined the current efforts in research and practice related to circular design, and it should be acknowledged that more extensive and exhaustive investigations and reviews of research in the field of design for sustainability would have yielded insights and lessons that may have helped the conceptualisation of circular design, the positioning of circular design in relation to sustainable development and sustainable design, the incorporation and development of relevant theory, and the deeper understanding of design practice.

Secondly, another limitation of the thesis is that the research is primarily situated in a limited geographical scope (northern Europe) in countries with proactive CE agendas and similar socioeconomic conditions. Therefore, the findings may not be representative of the entire EU and care should be taken when generalising findings to the entire European context.

Thirdly, a limitation of inductive research and PAR is inherently the risk for subjective bias, yet several efforts were made to address this through deploying multiple methods and data sources as well as clarifying the background and assumptions of the researcher (this limitation is further expanded on in section 3.3).

Finally, the last limitation relates to the inclusion of multiple perspectives. The research focused mostly on understanding the perspectives of design practitioners, except for study 2 and study 3 (paper E). In the circular design of products and buildings, it is vital to consider and include the perspectives of other actors that are equally important for the success of design interventions such as users, manufacturers, distributors, waste management, regulatory bodies, and policymakers.

# 6. Conclusions

The overall aim of this thesis has been to increase the understanding of how the CE is currently implemented in design practice and investigate ways of advancing circular design in practice. The thesis has investigated the implications of the CE concept for the role and practice of architects and industrial designers, and examined the role of stakeholder co-creation in supporting design for a CE. The following sections discuss the theoretical contributions and implications for practice. Finally, concluding remarks are provided and some directions for further research are outlined.

## 6.1 Theoretical contributions

This thesis has several scientific contributions. Firstly, the thesis contributes to a better understanding of the role of collaboration and co-creation in the context of circular design, as well as the (potential) role of designers in supporting co-creation and fostering collaboration for a CE. The findings can inform the development of theoretical models and prescriptive frameworks for design in a CE which comprehensively integrate supply chain collaboration and co-creation as a design element throughout different stages of the design process.

Secondly, while the interviews and survey deployed in study 1 were useful for gathering explicit knowledge about circular design, it was difficult to examine the implications for the design process and gather tacit (which cannot be verbally communicated) and latent knowledge (which refers to the thoughts and ideas of users on what has not yet been experienced but on which they may have an opinion based on past experiences) (Sanders and Stappers 2012). Here, the development of tools (e.g., the CfC) through the applied RtD approach, and testing them in workshop settings, can provide a legitimate method of inquiry to be able to learn about processes and challenges (e.g., design for a CE). While tools themselves are often presented as research outcomes or contributions, the use of tools in experimental settings to generate knowledge about processes and interactions in the context of circular design has so far been underexplored. RtD has been criticised for its lack of rigour, as the design research community has not yet firmly established what the approach constitutes; the criteria for evaluating the quality of the contributions; or discovered a common method for documenting the knowledge, methods, theories and insights that emerge from this type of research (Zimmerman et al., 2010). This issue emphasises the need for clearly articulating and documenting the theories and knowledge that result from the RtD approach and disseminating these to the cross-disciplinary platforms that can use these insights for the growth of the theory (Stappers, 2007). Overall, the CfC tool and insights from testing the tool in workshops can inform the development of new tools and approaches for co-creation that focus on the development of circular solutions in multi-stakeholder and multi-disciplinary settings.

Thirdly, the research has focused on the interrelated fields of industrial design and architecture, which is a scope of research that has not yet been widely covered. This allowed the researcher to draw upon relevant knowledge and insights related to CE from respective fields and provide insights which can spark further exchange and dialogue between the disciplines. Moreover, by synergising design perspectives, holistic approaches towards the CE are promoted. This can inform and inspire future research efforts on integrated design approaches and further collaboration between design disciplines.

Fourthly, during study 2, the researcher observed that methods and approaches for the longitudinal documentation and analysis of design and innovation projects are not well-established. While there are countless case studies on CE implementation, they are often a result of retrospective analysis and primarily provide 'static' snapshots of projects. Thus, they fail to capture the dynamic and iterative nature of the design process and potential learnings during and about different stages in the process. Considering that pilot projects for CE solutions are becoming more frequent and are crucial for wider adoption, these represent great value and potential to be further investigated from a longitudinal- and process- perspective. Considering the joint learning and network building that is necessary for COI, stakeholder perspectives and challenges are continuously changing, and the effectiveness of certain design strategies and approaches rely to a great extent on the 'right timing', aside from situational and contextual factors. Therefore, study 2 and its presented approach and method also contribute to a discussion and agenda on how to generate and convey insights from longitudinal studies and establish methods for data collection and analysis. Currently, there is limited research deploying PAR to longitudinally examine design and innovation processes for a CE. The PAR approach taken in this thesis can inform other research by showing the challenges and the opportunities, as well as contribute to a better understanding of the potential roles of (design) researchers in the transition to a CE.

Finally, the insights about the current factors that support and hinder circular design in architecture and industrial design can inform further research to study the implication in other design disciplines and geographical contexts to gain a better understanding of issues related to circular design in a wider global context. Furthermore, by increasing the understanding of the current challenges and enablers for practitioners, suitable design approaches and intervention strategies can be formulated that can further aid practice.

## 6.2 Implications for practice

The thesis has several contributions to practice. First, it provides deeper insights and an overview of factors that are currently supporting and hindering circular design in practice. Furthermore, some recommendations are provided that might practitioners in navigating future efforts concerning design for a CE.

Second, the thesis provides deeper insights on the role of co-creation in the context of innovation for a CE, and how co-creation can be leveraged in practice at different stages of the design process.

Third, a card-based circular design tool with a corresponding workshop manual is provided that can be used to conceptualise holistic circular design concepts, and to stage discussions and align perspectives in multi-disciplinary and multi-stakeholder contexts. The tool also helps to foster a holistic view towards the development of circular value propositions by distinguishing the relevant parameters in circular systems (the physical design, the business model, the value network) and stimulates the user in finding synergies between those parameters.

Finally, the thesis provides practitioners with a better understanding of the implications of the CE for the process, practice, and role of designers. Based on the findings of the research, an overview is provided of roles that designers can take to engage with circular design and the transition to a CE.

## 6.3 Concluding remarks

The transition to a CE represents great challenges and opportunities for designers. More than ever, designers will have to anticipate how artefacts such as products and buildings are used and change over time, to design them in ways which facilitate lifetime extension and closing of resource loops. In the context of the CE, the focus of designers shifts further away from the creation of physical artefacts to the creation of circular systems, business models, and collaborative value networks. Thus, ultimately helping organisations to look ahead and render the pathways towards circularity tangible. Consequently, the CE expands the scope of design projects, drives the integration of new knowledge areas in the design process, and demands interdisciplinary collaboration and co-creation. In this light, the thesis examined both perspectives across industrial design and architecture, and argues that the further integration of and knowledge exchange between design perspectives will benefit the holistic development of products, building components, and buildings in line with CE principles.

The findings of this thesis indicate that the CE concept has gained substantial traction amongst design practitioners; the majority of surveyed practitioners have participated in projects with a focus on CE and also actively undertake efforts to advance circular design. Although some of the challenges related to circular design can be addressed directly (through expanding knowledge and collaborations), the major challenges that inhibit circular design practices currently are mostly

*Table 2.* A summary of the contributions of this thesis connected to the research questions.

| RQ | Contributions to theory | Contributions to practice |
|---|---|---|
| 1 | • Creates a better understanding of how the CE concept is currently interpreted and operationalised within architecture and industrial design.<br>• Pinpoints the conceptual ambiguity of circular design as a concept.<br>• Identifies fundamental differences in how circular design is currently understood and applied across architecture and industrial design.<br>• Contributes to a discussion on the interaction and the intersection between the disciplines of architecture and industrial design in the transition to a CE, to promote the synergy and cross-pollination. | • Provides practitioners with relevant insights into how working with circularity in practice can affect the design process and the role of designers, lead to transformations in design agencies, and understanding of external factors that can affect integration of circular design.<br>• Provides design practitioners with relevant insights into specific roles and opportunities they can take to engage further with the CE concept and contribute to the acceleration of the CE transition.<br>• Informs and supports practitioners to navigate future endeavours and challenges in the context of design and innovation for a CE. |
| 2 | • Provides an overview of factors currently hindering and supporting circular design, and insights into actual needs of practitioners.<br>• Identifies that the most prevalent factors hindering circular design are mostly beyond the control of designers and require further coordinated efforts between research, industry, and policymakers.<br>• Provides an explorative framework and metrics to measure circular design activity of practitioners based on incorporated circular strategies.<br>• Provides insights into the characteristics and perspectives of design practitioners that are active in terms of circular design strategies which can inform theory development. | • Provides an overview of (regional, national, international) networks and initiatives developed to promote circular design which provide fruitful ground for knowledge exchange and collaboration, related to design for a CE.<br>• Increase understanding of the current challenges, efforts, foci, organisational changes, and knowledge needs across architecture and industrial design practice in relation to circular design.<br>• Increase understanding of to what extent the CE concept has reached out to practice, and gives insights into the focus and characteristics of practitioners that are highly active in terms of CE. |
| 3 | • Contributes with longitudinal insights on the role of co-creation in the process of design and innovation for a CE considering the dynamic nature of different activities, stages, and stakeholder perspectives in the design process. This contributes to the development of theory and prescriptive methods for co-creation in the process of COI and development of CE value chains.<br>• Contributes to approaches and methods for longitudinal analysis of case studies on design and innovation processes for a CE.<br>• Informs theory development on the role of prototyping as a process, and prototypes as knowledge objects, in the development of circular value propositions. | • Outlines practical lessons for co-creation in the process of design and innovation for a CE, relating to the alignment of stakeholders' expectations and project vision, the willingness of stakeholders towards external collaboration, and the presence of a neutral collaboration platform and facilitator.<br>• Provides insights on how practitioners can leverage their role as connectors and facilitators in the CE transition by deploying co-creation and participatory design techniques to foster stakeholder collaboration.<br>• Informs about the supportive role of co-creation in COI and the importance of co-creation activities early in the design phase with the supply chain. |
| 4 | • Increase understanding of how the development and use of design tools in workshop settings can support inquiry about processes and approaches of circular design.<br>• Provides a better understanding of how card-based circular design tools can facilitate stakeholder alignment and co-creation, and stimulate holistic thinking through the combination of technical, industrial, and business model strategies.<br>• Provide insights from the development and testing of the CfC that can support the further development of theoretical frameworks and prescriptive methods for the co-design of circular value propositions. | • Provides a tested toolkit including manual of a digital, card-based circular design tool CfC to support practitioners in the conceptualisation and co-design of holistic circular solutions, and the process of staging discussions on circular strategies in multi-stakeholder settings.<br>• Practical insights on how the use of tools can support collaborative ideation in digital and on-site workshops<br>• Provides insights and lessons about co-creation in COI in terms of when (what stage) and how (what type of activities) to facilitate co-creation throughout the development of circular value propositions. |

beyond the control of designers. These are likely to require coordinated efforts by governments, design practice, industry, and research to be addressed accordingly. The thesis posits that designing for a CE requires holistic and systemic approaches that go beyond perceiving circularity as a technical design challenge which can be addressed through design projects as temporary endeavors and technical design interventions. Instead, successful design efforts in the context of a CE rely on the concurrent development of circular products and business models, and extensive collaboration with all relevant actors in the value network, during the design process and beyond throughout the lifecycle of artefacts. The investigated design practitioners expressed a need to move from short-term engagements towards extended partnerships, from transactional to more relational modes of design practice. This perspective is especially present amongst architects, who indicated shifts and expansions regarding their role within the value chain of construction.

Given the nature of circular design as a collaborative challenge, participatory design approaches and co-creation should be considered integral components in design for a CE, and the role of designers in facilitating connections and collaborations between upstream and downstream actors should not be overlooked. Moreover, the current state of the CE transition demands pilots, real-life experimentation, and prototyping to display the viability of circular value propositions and promote their practical implementation. In this light, the thesis provides valuable longitudinal insights about the role of co-creation and prototyping throughout the process of design and innovation for a CE based on the case of the circular kitchen.

To advance circular design in practice, the potential of designers in fostering collaboration towards a CE and the role of co-creation needs to be articulated and integrated more clearly in the frameworks and dissemination of circular design, and the insights from this thesis can support the development of guiding frameworks and prescriptive methods for co-creation in circular design. The CE concept currently is shrouded in ambiguity, and the thesis found that different practitioners interpret and apply the CE concept in fundamentally different ways. To stimulate holistic approaches towards circular design, it may therefore be worthwhile to further develop coherent conceptualisations of circular design based on common guiding principles and theoretical underpinning to aid alignment and practical implementation. Moreover, there is a need to develop suitable ways of assessing how decisions at the design stage affect the circularity of a given solution attuned to the workflow and process of designers (both from an environmental and economic perspective).

To address the need for collaborating and aligning perspectives on CE strategies in multi-disciplinary and multi-stakeholder contexts, the developed card-based circular design tool 'Cards for Circularity' can help to stage discussions on definitions and strategies regarding circularity and support a co-creative and holistic approach towards the development of circular concepts in early design phases. Finally, designers will need to be equipped with the knowledge and suitable prescriptive frameworks and methods to effectively deploy stakeholder co-creation as a part of the design process and contribute to the formation of circular value networks and ecosystems.

## 6.4 Directions for further research

Due to the explorative nature of the research design and the expansive scope of the thesis, the research conducted in this thesis in some ways just 'scratched the surface' and might have benefitted from a more narrowly defined scope. Nevertheless, the scope of the thesis enabled the bridging of different fields and research areas and provided fruitful avenues for further research.

Firstly, the research largely focused on the perspective of designers and gathered insights from the perspective of design practice. Although study 2 also provided longitudinal insights from the perspective of companies and manufacturers going through the process of innovation for a CE, there is a need to further investigate the perspective and role of other actors during the design of circular value propositions. For example, how upstream and downstream actors (e.g., material developers, recycling facilities) are (and could be) included in the design process of circular value propositions. Moreover, this thesis has examined the COI process primarily based on a single case study in the context of the kitchen industry. Further research could also focus on extracting longitudinal insights and lessons from new and ongoing pilots of circular value propositions in other contexts, to further convey the feasibility of such propositions and gather relevant knowledge that could support further practical implementation.

Secondly, further research could focus on creating a better understanding of the actual needs of designers and architects working in practice concerning design for a CE. What kind of supportive frameworks, and prescriptive methods and tools are currently used to engage with circular design, and what is needed the most? Furthermore, one direction could be to investigate how designers can be supported in assessing the effects (e.g., through qualitative assessment) of material and design choices on the circularity potential of different proposals during the early-stage design process to support informed decision-making when there is limited technical data or time for more advanced environmental impact assessments (i.e., LCA). Another direction relates to investigating how design practitioners go about the participation and inclusion (how, to what extent, at what stage) of supply chain stakeholders when designing circular value propositions, and how they currently deploy participatory design and co-creation techniques to enable this. This could provide valuable case-based insights for practitioners and support the development of prescriptive methods for the co-design of circular value propositions.

Thirdly, following up on the second point, further research could focus on investigating and classifying the plethora of circular design guides, methods, and tools that have been made available to designers and map these against the identified needs of practitioners, and the stages of the design process. In addition, to ensure practical adoption and impact, there is a need to then evaluate the efficacy and effectiveness of these different methods. More precisely, an overview can be made of existing prescriptive frameworks that support collaborative innovation and co-design of circular value propositions and assess how these frameworks can be operationalised and adapted to the needs of designers and other practitioners.

Finally, this research has made it apparent that knowledge on circular design is primarily autodidactic and that there are many organisations, hubs, and networks to promote and distribute knowledge on circular design. There are examples of initiatives on a regional, national, and governmental level, and these initiatives appear to have an important role in facilitating knowledge exchange about circular design and collaborations in the context of a CE. Given that the primary challenges of designing for a CE are beyond the direct influence of designers, some relevant insights may be gathered by investigating the role of these initiatives in the transition to a CE, and how they address the challenges currently encountered in practice.

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# Appendix A

## The circular kitchen in Sweden

The following section provides a detailed case study description of the CIK project in Sweden, which was carried out as a part of paper C.

### Analysis phase

Introductory meetings took place between the research team and the project partners concerning potential directions for the project and helping the researchers gain a better understanding of the current knowledge, challenges, and efforts in relation to sustainability and CE within the organizations. The project team identified an opportunity to investigate how kitchens can be designed in a flexible manner, to be able to adapt to changing circumstances (e.g., change of owner or tenant) and different preferences throughout lifecycles.

A consortium workshop took place including Chalmers, TU Delft, various stakeholders from the Dutch supply chain (e.g., kitchen manufacturer, appliance manufacturer, housing companies) and the Swedish kitchen manufacturer. Preliminary discussions took place for the design of circular business models and the kitchen within the Swedish context.

The project faced a couple of challenges. The assortment manager of the kitchen manufacturer (who was a driving force for the project and the internal sustainability agenda) left the company and the kitchen manufacturer raised concerns regarding available staff to assign to the project. The project proposal included a deliverable of a first physical prototype of a kitchen design based on circularity principles by the end of the first year, and during the rest of 2018 various meetings and three workshops (see table A1.) were organized with the kitchen manufacturer (as the key partner to produce this prototype). The first workshop took place at the kitchen manufacturer and included a factory tour, a presentation of a market analysis carried out by the researchers, a stakeholder mapping workshop, and an innovation workshop that focused on kitchen design for different demographics. The second workshops featured a presentation by the research team of conceptual directions for a circular kitchen design, and a circular business model canvas workshop. During a third workshop, the researchers explained the circular economy concept in further detail, and facilitated a future vision workshop (for 2030 and 2050) on how CE principles could be integrated into the business, and a co-creative session took place with the purpose of conceptualizing a circular business model and service solutions. Through the workshops, the kitchen manufacturer particularly showed interest in two directions: (1) adopting durable materials with a higher potential for recirculation and (2) the development of a PSS and service-based revenue model that could enable maintenance and repairs and avoid the premature disposal of kitchen furniture.

The research team initiated user studies (focus groups, interviews) with households to investigate how contemporary kitchens are used (and changed throughout the lifetime) to adapt to preferences and demands of households.

*Table A1.* Overview of the co-creation workshops.

| # | Role | Participants | Purpose | Activities | Outputs |
|---|---|---|---|---|---|
| 1 | 2 Jul 2018 | CEO (Owner)<br>Product range manager<br>Product coordinator<br>Product manager<br>Constructors (2)<br>Concept marketeer<br>Researchers (5) | Project introduction<br>Relationship building<br>Market analysis<br>Stakeholder mapping<br>Idea generation | Company presentation<br>Factory tour<br>SWOT analysis<br>Stakeholder analysis<br>Innovation workshop | Stakeholder map<br>Company and market analysis<br>Ideas for promoting circularity in kitchens |
| 2 | 11 Sept 2018 | CEO (Owner)<br>Product coordinator<br>Product manager<br>Constructors (2)<br>Researchers (5) | Evaluate concepts<br>Identify circular business model opportunities<br>Identify relevant stakeholders | Concept presentation<br>Concept evaluation<br>Circular business model canvas workshop<br>Stakeholder mapping (continuation) | Concept evaluation and selection<br>Ideas for circular business model |
| 3 | 12 Oct 2018 | CEO (Owner)<br>Product coordinator<br>Marketing manager<br>IT manager<br>Customer service manager<br>Researchers (5) | Agree on circular goal/ vision for project/company<br>Further development of selected concept | Define circular vision project and company<br>Discussion concept selection<br>Evaluation opportunities/ challenges for selected concept | Circular vision 2022/2030<br>Concept evaluation<br>Prototype plan |

## Protopying phase

The research team led the development of the prototype, the kitchen manufacturer was assigned with the fabrication of the prototype. Due to the limited time (approximately 3 months) and limited in-house prototyping capabilities at the kitchen manufacturer, a collective decision was made to produce a conventional kitchen but based on moveable kitchen modules on wheels. This enabled further investigation of how kitchens could adapt over time to changing preferences and demands (e.g., from different users), to avoid premature alterations and disposal of kitchens.

During a workshop organized with the appliance manufacturer to discuss the role of kitchen appliances in the project and define a research agenda, it became apparent that the company had been acquired by a larger consumer electronics concern, and unclarity existed regarding their further participation in the project.

Material research efforts were conducted by the research team to explore and identify alternative materials for kitchen furniture. Conventional materials in the kitchen furniture industry (i.e., MDF, chipboard) were found to offer a relatively short lifespan and limited potential for recirculation, whereas materials like solid wood and bio-composites, respectively, were found to offer the potential of extended lifespans and improved recycling practices. The researchers initiated a meeting between a bio-composite producer and the kitchen manufacturer, revealing a significant potential of bio-composites for kitchen application but requiring radically different manufacturing capabilities and major investments from the kitchen manufacturer.

Through close collaboration with the kitchen manufacturer, the test kitchen based on standard components (prototype 0) was manufactured and installed in a tenantless testing room of a living

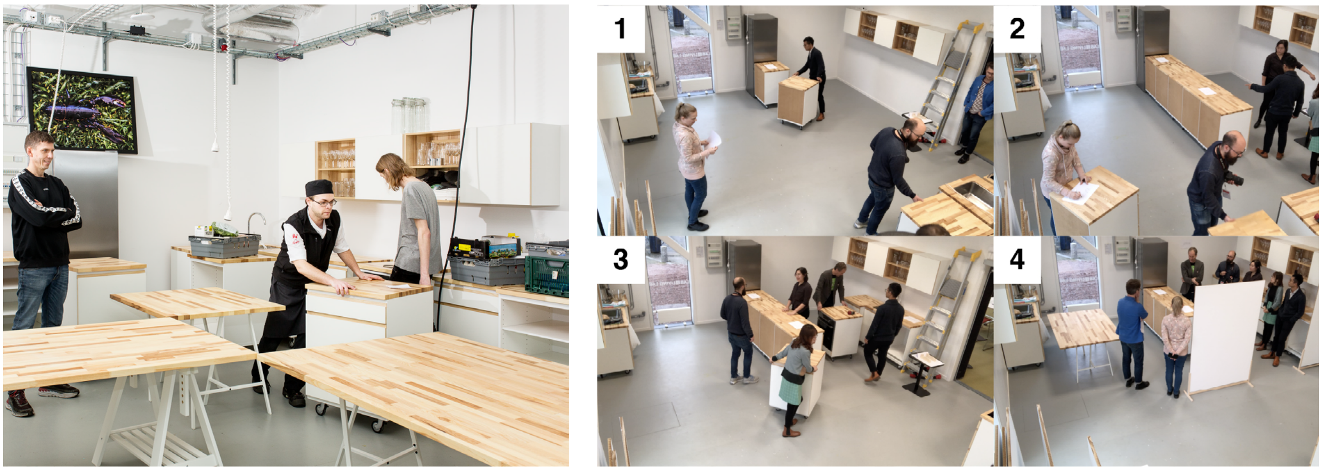



*Figure A1.* First prototype kitchen installed in the living lab on the university campus during consortium workshop with professional cooks (left) and user studies (right).kitchen scenario (right).

lab at the university campus to enable testing and workshops with different types of users (e.g., cooking sessions, kitchen layout planning sessions). A consortium workshop took place where the prototype was presented to the Swedish and Dutch partners and evaluated through a cooking session with professional cooks (Figure S.1., left). During the workshop, the companies presented ongoing efforts and ambitions regarding circularity. Afterwards, a vision workshop was organized to define a future vision on circularity in the kitchen industry and a back casting approach was used to translate the outcomes to concrete goals for the CIK project.

The research team conducted various user studies with the kitchen prototype to learn more about the spatial and functional preferences of kitchens according to different types of users (figure A1).

### Proof of principle

The prototype became a useful resource in work of students (e.g., thesis projects, course work) and the results provided valuable insights to the overall research project and directions for further research.

During a workshop organized with the kitchen manufacturer, preliminary research findings were presented by the researchers and circular design strategies were collectively ranked, resulting in three key principles: 1) integrating kitchen refurbishment services in the business model 2) undertaking a pre-study on developing a PSS that can enable a service-based revenue model, and 3) identifying alternative board materials with lower environmental impact and similar or lower economic costs than current standard board materials.

Efforts were made to engage relevant actors in the supply chain and three of the kitchen manufacturers clients (1 housing association, 2 construction companies) were contacted. Individual meetings took place with each company, the companies showed interest in the project and some already had an agenda for circularity. Afterwards, a common workshop was organized together with these actors, indicating that the costs associated with a circular kitchen design were a main concern. The workshop participants concluded that the next step would be to test a circular kitchen prototype in a real-life scenario (e.g., community room or guest apartment) where it would also be possible to evaluate the (dis)assembly procedure of a 'flat-pack' kitchen construction concept.

### Proof of concept

The researchers explored a modular kitchen construction to enable easier exchange of parts and components (e.g., doors, panels) that are prone to damage and likely exchanged during the lifecycle of the kitchen, thus facilitating maintenance, repair and exchange routines to extend kitchen furniture lifespans. Plans progressed for a second demonstrator prototype, a tenant-occupied apartment in the living lab was considered an ideal real-life setting for evaluation and testing. An external design consultant was subcontracted to further develop the concept into a manufacturable product together with the researchers.

Bi-weekly meetings took place with the design consultant to steer and co-develop the concept further. The consultant initiated contact with an aluminium manufacturer to evaluate the potential of using aluminium profiles as the material for the kitchens base frame. Due to environmental and technical concerns regarding this material, plywood was identified as an alternative material for the frame solution, offering a relatively high durability and lower environmental impact.

Because of the ongoing Covid-19 pandemic, the kitchen manufacturer announced that they were not able to produce the next prototype and an alternative partner had to be identified for the prototype production.

The final concept developed by the design consultant and research team was presented to the kitchen manufacturer (See figure A2). The kitchen manufacturer responded positively and showed interest in the further development of the concept into a prototype and made the decision to assign an engineer to the project to support further development.

### Prototyping phase

Bi-weekly work sessions took place between the engineer and the research team to enable progress in-between the sessions and collaboratively elaborate and decide on technical details of the design such as materials, dimensions, and components.

*Figure A2.* Proof of concept presentation featuring modular cabinet construction (left) and kitchen scenario (right).

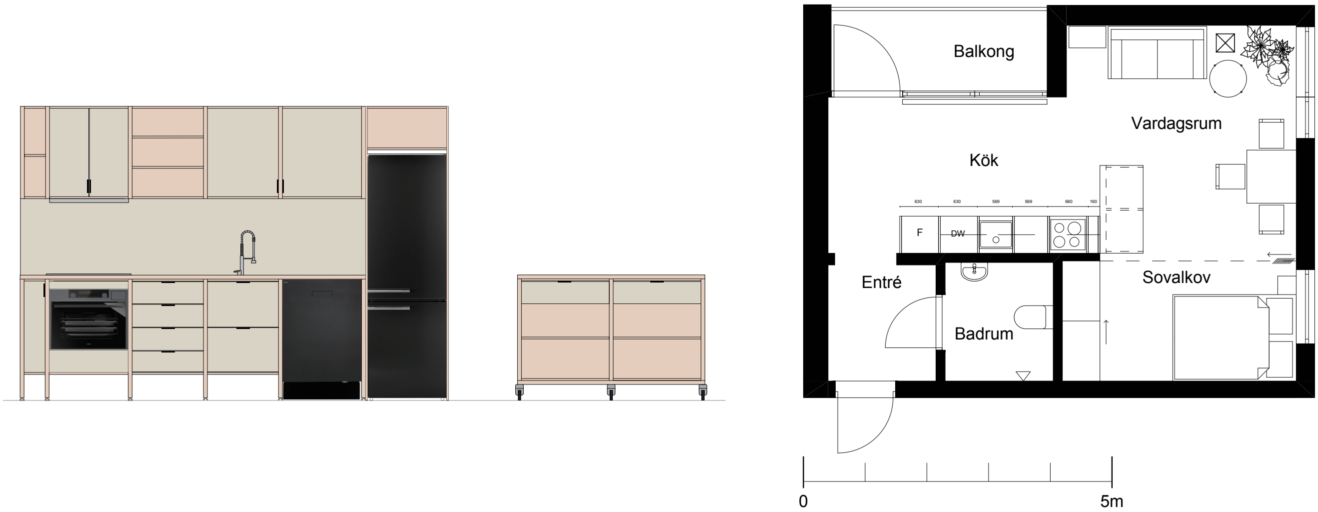



*Figure A3.* Impression of prototype kitchen for installation in apartment living lab (left) and floorplan (right).

The researchers set up contact with a Finnish plywood manufacturer offering plywood panels based on bio-based lignin adhesives instead of fossil-based phenols. The manufacturer showed interest in the project and decided to sponsor the project by providing plywood panels to produce the prototype.

Contact was initiated with a housing developer that is interested in the project and offered the opportunity to place additional two prototype kitchens in apartments of an early-phase building project targeted towards seniors. Floor plans were prepared for the installation of three prototype kitchens, one in an apartment in the living lab (figure A3.), and two in apartments of the housing developer.

Meetings took place with the appliance manufacturer to discuss the upcoming prototypes and the integration of kitchen appliances in the kitchen prototype. Since the kitchen manufacturer lacked in-house prototyping capabilities, a carpenter was subcontracted to produce the prototypes. The kitchen manufacturer expressed confidentiality concerns regarding sharing the technical drawings of the kitchen concept with external parties and asked for signed NDA agreements.

Several prototype cabinets were produced by the kitchen manufacturer (through an external party) showcasing the plywood design construction (figure A4.) and the prototypes were ocularly

*Figure A4.* Prototype cabinets showcasing the plywood construction based on flexible furniture connectors.

evaluated by a few members of the kitchen manufacturer and the research team. The potential of the kitchen design is displayed, several challenges are identified leading to changes in the dimensions of the plywood components of the kitchen. Another kitchen cabinet prototype is produced by the contracted carpenter and placed at the university for evaluation. Various technical challenges are identified relating to warping of plywood panels, the stability and weight of the cabinet components, and the connections between different components.

The kitchen prototype is installed in an apartment of the living lab (see figure A5). The process of deconstructing the old kitchen and installing the new kitchen is carefully observed and documented by the research team to evaluate the overall construction and installation process. Further testing and evaluation of the prototype is continuously taking place with the researcher-tenant of the apartment. A final workshop took place to conclude the project, evaluating the prototype, exchanging key learnings and experiences, and presentations of findings by the research team.

### Evaluation phase

The kitchen prototype in the living lab is ongoingly tested and evaluated through daily use by the researcher-tenant, through organized kitchen sessions (i.e., cooking and eating) with diverse user groups, and through field visits (e.g., by professionals, researchers, students) where visitor responses are captured through observations and surveys. Through studying the daily use over several months (and potentially years), it will be possible to study the functionality of the kitchen over time, the wear and tear of the components, and potentially repairs and alterations. The

*Figure A5.* Prototype kitchen installed in living lab, featuring a modular plywood construction and moveable kitchen island to adapt to changing social settings and functional demands.

insights gathered through the construction, installation, and use of the prototype were thoroughly documented and will serve as input for the further development of the kitchen design during a follow-up project running from 2021 to 2023, that will focus more on the further development from prototype to market implementation. During this project, the next iteration of prototypes will be installed (and tested) in two apartments of an early-phase building project targeted towards Seniors in the proximity of Göteborg, Sweden.

# Appendix B

The following section provides a detailed description of the CfC toolkit which was developed and utilised in the context of paper E. The material can be utilised and adapted in future research. Both an overview of individual cards is included as well as a workshop manual that can be used to organise workshops with the CfC.

## Cards for Circularity (CfC) cards

This section provides an overview of the individual cards included in the final iteration of the CfC toolkit in study E. The CfC toolkit is a further iteration of the first version of the cards based on the circular building component (CBC) generator by Van stijn & Gruis (2019). Examples of this first version are shown in figure A6 and A7. Please note that the images on the cards that refer to real cases and solutions are blurred due to copyright and license considerations.

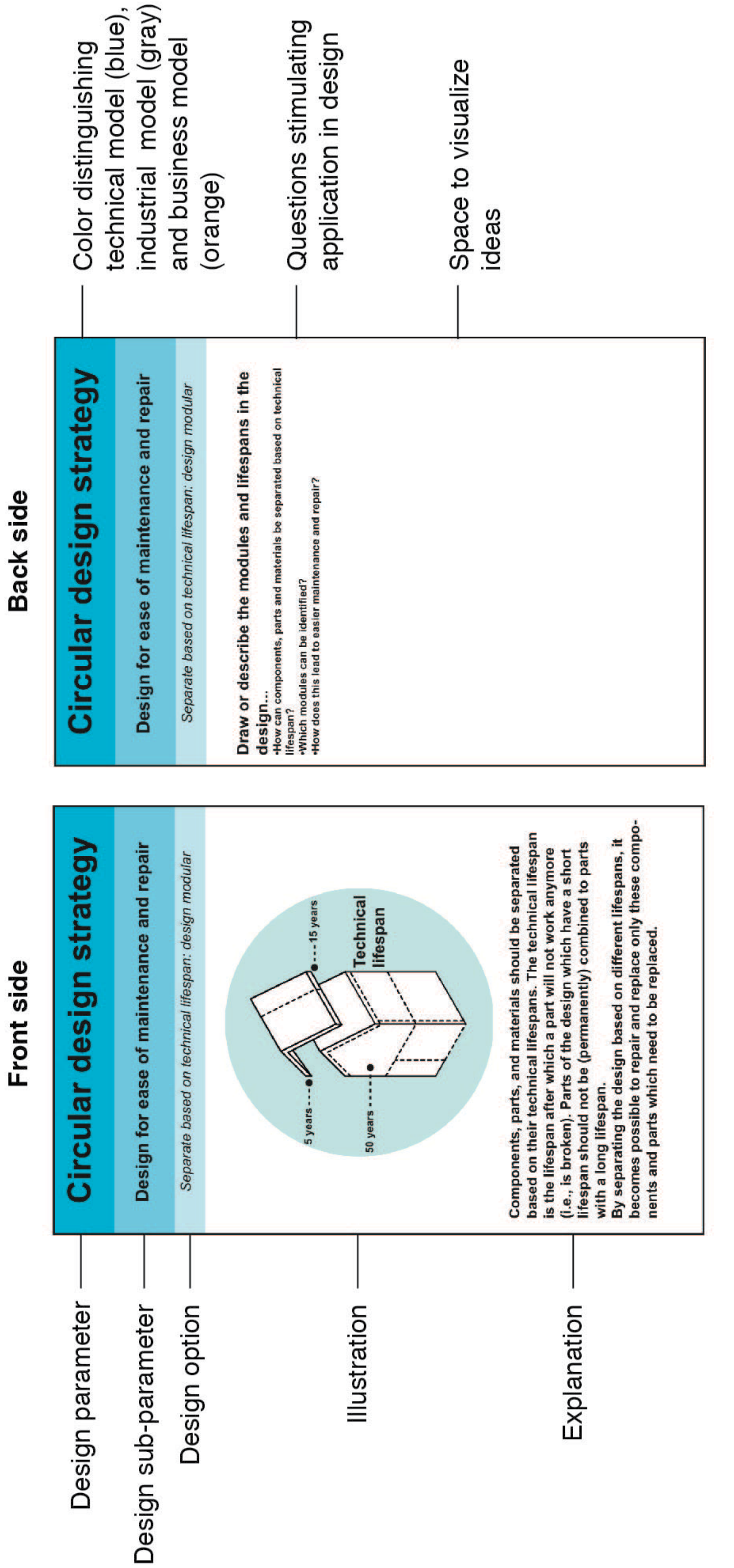



*Figure A6.* An example of a card for the design parameter 'Circular design strategy' and sub-parameter 'Design for ease of maintenance and repair', and explanation of card elements.

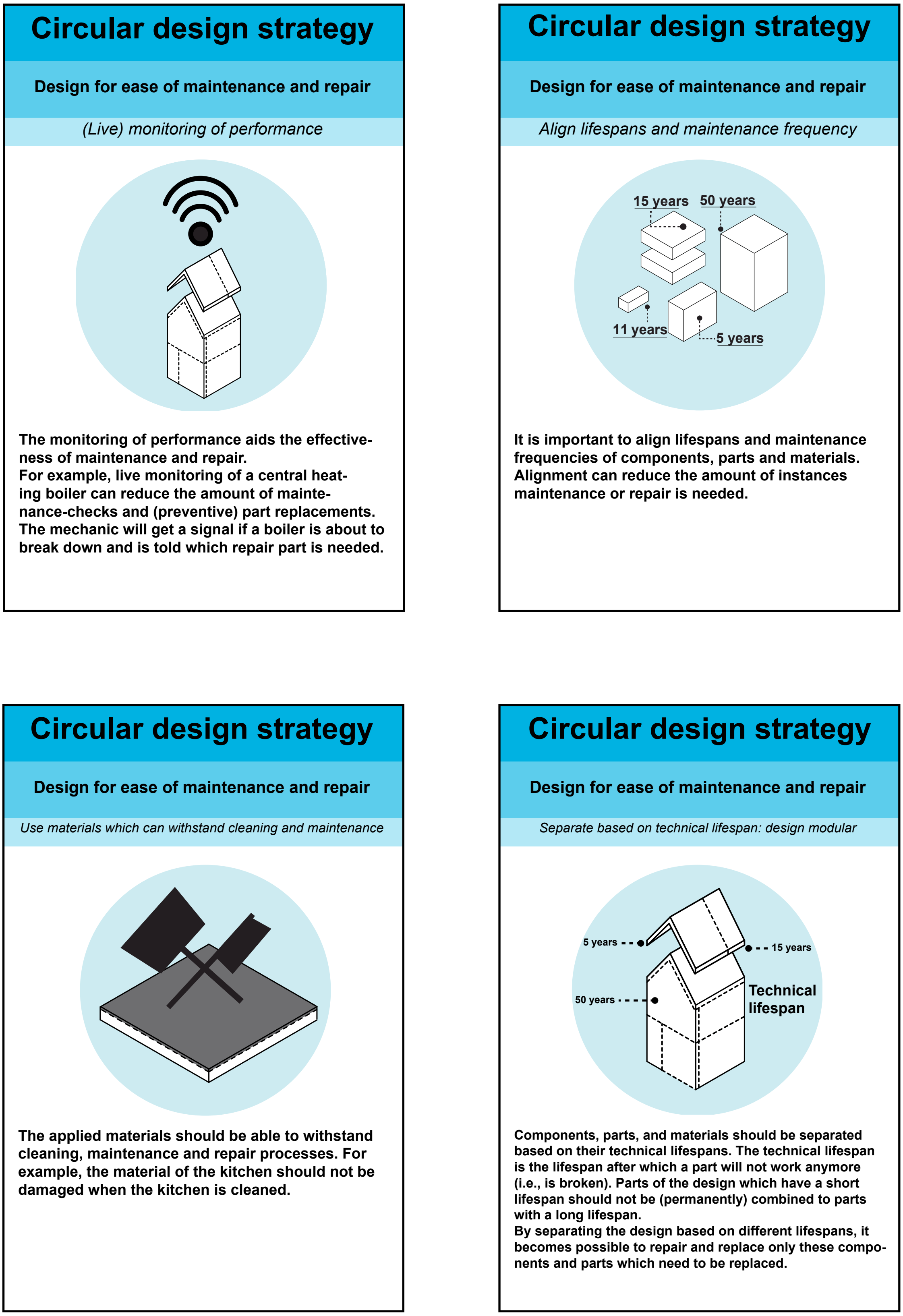



*Figure A7.* An example of different cards for the design parameter 'Circular design strategy' and sub-parameter 'Design for ease of maintenance and repair'.

How might we..

## use biological materials to increase circularity?

Biological materials are renewable and can be regenerated, and returned to the biosphere after use. Examples of biological materials are food, cotton, (untreated) wood, and bioplastics.

*Figure: The use of untreated wood in the built environment is ages old. In the European Alps for example, some houses are cladded with untreated wood. This wood ages naturally over time, and when the time comes to replace the cladding, it can be brought back in the biosphere directly.*

**Biological materials** **1**

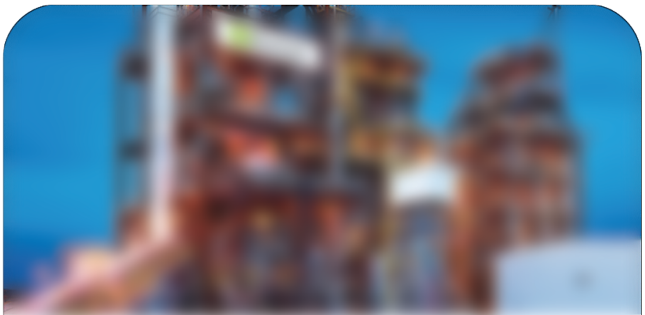
How might we..

## use technical materials to increase the circularity?

Technical materials are non-renewable, but typically have a high durability and/or can be cycled many times keeping a high utility and value. Examples of these materials are metals, ceramics, bricks, (treated) wood and plastics.

*Figure: Although one stainless steel bottle is much worse than one plastic bottle due to the energy used and emissions in production, the choice may be justified if it has a very long lifecycle.*

**Technical materials** **2**



Which..

## type of energy source can increase circularity?

Many processes such as production and transportation need energy. It is generally preferable to use renewable energy sources such as solar, wind, hydro instead of oil and gas.

*Figure: Canadian firm Enerkem has developed a way to turn trash that can't be recycled into gas that can be used to make biofuels like methanol and ethanol. These can then be used to power transport like cars.*

**Type of energy use** **3**

At which..

**scale level can we increase circularity the most?**

Developments take place on different scale levels. Such as: built environment, building, building component, product, part, material. These scale levels offer different opportunities to increase circularity.

*Figure: At the Sydney fish market the roof structure is set in place and is not neccesarily circular, while the stands that change owner more often are made adaptable.*

**System elements 4**

How might we..

**enable circularity by being aware of the amount of elements?**

Buildings or products consist of different system elements. By being aware of the number of elements and the amount of resources used per element, you can focus on where the impact is the largest.

*Figure: Some facades contain several windows while others are completely made of windows. Knowing the amount of windows in this case is crucial when deciding wether to make the windows as circular as possible, or to focus on another element.*

**Amount of elements or resources 5**

How might we..

**increase circularity through the number of lifecycles?**

The number of lifecycles indicates how many times a component, part or material, is re-looped (i.e., repaired, re-used, refurbished, recycled). By reflecting on the number of lifecycle(s), suitable strategies to make it circular can be determined.

*Figure: Stora Enso produces bio-composites, a blend of plastic and 30-50% wood fibres.The material can be reprocessed up to 5-6 cycles while maintaining material quality.*

**Amount of lifecycles 6**

How might we..

**increase circularity through the expected lifespan?**

The expected lifespan indicates how long you expect a product, component or part to last. By mapping the lifespan of your product and its component, parts, and materials, strategies for making it circular can be determined easier.

*Figure: This office chair by Flokk features a patented upholstery fastening technique that avoids the need for glues or solvents. This is beneficial as the textile cover has a different lifespan than other components and is likely to be replaced before.*

**Expected lifespan 7**

How might..

**awareness of the product maturity level increase circularity?**

Products move between maturity levels. First they are introduced to the market, experience development and market growth, reach maturity and can decline. The right strategy to make a product circular can be influenced by the maturity level.

*Figure: Central heating with boilers in the Netherlands are likely to be replaced by heat networks and heat pumps. It is therefore a product in decline, making long life design strategies less valuable.*

**Lifecycle stage 8**

How might we..

**design for material reduction?**

Consider reducing the amount of materials used in a design, for the production and also during the course of it's life. This can help reduce the depletion of natural resources and result in less environmental impact.

*Figure: The Miito kettle does not feature a kettle, but uses a heating element rod to heat the water directly in the container of your choice.*

**Design for material reduction 9**

How might we..

**design for energy reduction?**

A significant part of the environmental impact of electronic products is related to energy consumption in the use phase. By minimizing energy usage, or recovering energy in processes this impact can be drastically reduced.

*Figure: Kvadrat developed roller blinds featuring a metallised textile that allows it to function as a thermal insulator, preventing heat entering when hot and heat escaping in winter.*

**Design for energy reduction 10**

How might we..

**design for attachment?**

Attachment can be achieved in a number of ways. For example, through emotional desirability, a timeless design, user trust, ease of use or surplus quality. These may all lead to longer use and therefore less resources used in total.

*Figure: The RT20 radio and many other Braun products designed by Dieter Rams are widely regarded as timeless designs, the focus on functionality and limited use of color makes for products that are less sensitive to changing trends.*

**Design for attachment 11**

How might we..

## design for reliability and and durability?

By designing for reliability and durability, people feel like they can rely on products and the lifespan of products can be lengthened. Early disposal of the product can be avoided by by for example, anticipating on new regulations, dimensionig for unintended use or over-dimensioning critical parts.

*All miele household devices are tested to guarantee a functional lifespan of 20 years. A long lifespan requires service and repair, Miele therefore runs it's own servicing organisation.*

**Design for reliability and durability 12**

How might we..

## design for standardisation and compatibility?

Standardization of parts, measurements and joints facilitates easy re-use and repair. One component or part can simply be replaced with another one. Consider the compatibility with older and future versions.

*Figure: The vitsoe 606 shelving system uses standardized components and measurements that have been the same since the creation in 1960 which encourages repairability and upgradeability.*

**Design for standardisation and compatibility 13**

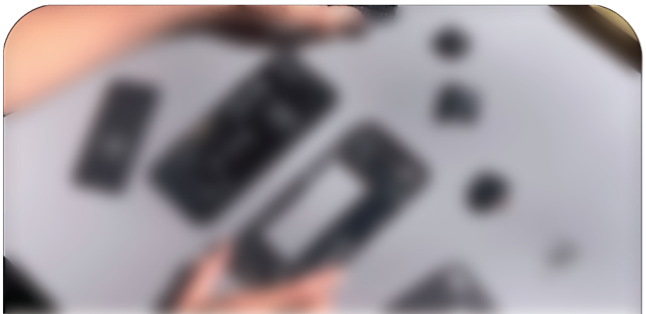
How might we..

## design for ease of maintenance and repair?

It is important to minimize the number of components, and think about their invididual lifespans. This will help to define the best strategies for maintenance and repair, and optimize the required sequence for it.

*Figure: Cars have always been expensive and repair intensive, and therefore have been optimized for maintenance and repair. Getting replacement parts and regular check-ups has become a standard procedure and an industry on itself, that supports lifetime extension rather than disposal.*

**Design for ease of maintenance and repair 14**



How might we..

## design for upgrades and adjustments?

Allow components, parts and materials to be extended, updated and upgraded to fulfil future needs and preferences. Separate components in the design based on their functional lifespan, this allows for easier repair of parts that are more likely to break.

*Figure: Fairphone is a fully modular phone that can easily be repaired by the user themselves and upgraded with new components. They provide detailed repair instructions and a repair service if the user is not able to perform their repairs.*

**Design for upgrades and adjustments 15**

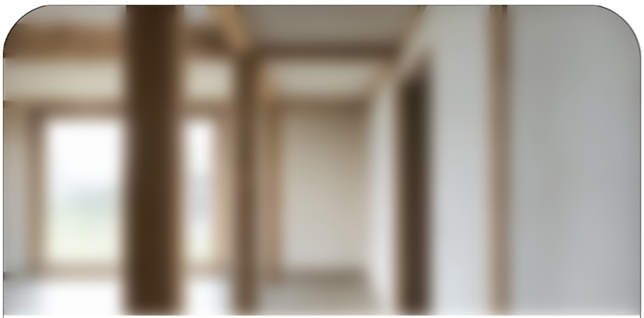
How might we..

### design for dis-, and re-assembly?

Products and parts that are easily taken apart, facilitate easier replacements, repair and recycling. Pay attention to the order in which a product should be (dis)assembled and use flexible connections that not need to be destroyed or damaged for disassembly.

*Figure: Frustrated with e-waste, Tomi Laukkanen proposed three rechargable products that can be easily disassembled and repaired, with clear instructions on the packaging.*

**Design for disassembly** **16**



How might we..

### design for recycling and biodegradation?

After use, materials can be recycled to be used as a resource for new production, or can be brought back into the biosphere to prevent material loss.

*Figure: Biobased building is done by using materials that come from biological sources. These materials are generally applied untreated, so they can be brought back into the biosphere after use to be biodegraded.*

**Design for recycling** **17**

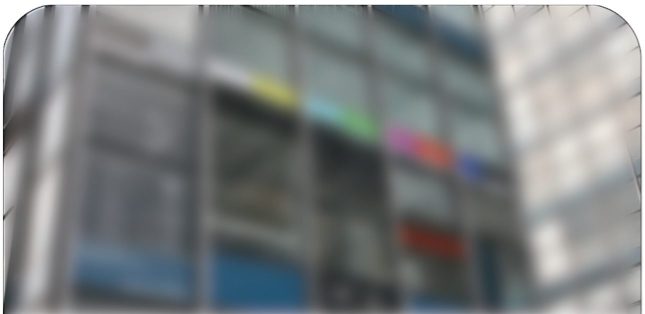
Which..

### industrial partners can you collaborate with?

Closing resource loops and developing circular solutions requires new industrial partners, new roles of existing partners and new types of collaboration. Think about what types of partnerships could lead to effective use of resources, reloop activities and avoid waste.

*Figure: Toast Ale brews beer from surplus bread received from bakeries, avoiding food going to waste.*

**Partners in supply chain or value network** **18**



How might..

### activities in the supply chain be assigned to enable circularity?

Although some activities may remain the same compared to a linear product, assigning them in a different way may enable circularity. For example, think about financing, manufacturing, transporting, selling and installation of your solution.

*Figure: In the Façade leasing project done at the TU Delft, a consortium of partners were set up with assigned roles to enable a new financial model (leasing), that would in turn incentive a circular design.*

**Activities** **19**

Which..

## reloop activities could increase circularity?

Reloop activities turn a linear supply chain into a circular one. Through, for example, maintenance, repair, recovery, re-use, refurbishing and recycling, products and materials can be used longer, preventing waste and emissions. Think about how you can incentivize such activities.

*Figure: Most supermarkets provide a bottle returning service, this is an efficient way to circulate resources. The deposit fee creates a strong incentive for people to return bottles.*

**Re-loop activities** **20**

How might we..

## enable circularity through (re-)production processes?

Different production processes, such as casting, moulding, welding, joining, 3D printing have different associated environmental impacts and different potential to enable circularity.

*Figure: Rather than aiming to use less and less material, Caterpillar creates heavy machinery that is intended to be returned and remanufactured a number of times.*

**(Re)production processes** **21**

What kind of..

## facilities are needed in the use cycles of your product?

Reloop activities need to take place to create a circular supply chain. For example, collecting products, parts and materials when they reach end-of-life, or repair and maintenance practices. To have these activities take place, (new) facilities need to be determined.

*Figure: In many european countries second hand clothing is collected in public containers. It is then sorted in specific facilties, and sold in second hand shops. All three require a specific facility to take place.*

**Facilities for activities** **22**

How might we..

## make the product become part of a whole?

A product is part of a larger environment and consists of smaller components and parts. Thus, different system levels. When developing a product, awareness of these different smaller and larger system levels can offer new opportunities for circularity.

*Figure: Fairphones, like any phone, consists of smaller components and parts that become the bottle neck for a long life e.g. due to technological development. Fairphone sells seperate parts to upgrade the phone and extend its lifespan.*

**System elements** **23**

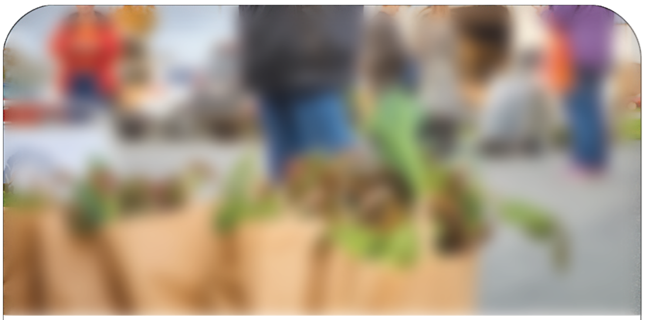
How might we..

## enable circularity through the mode of transportation?

Transport can have a high environmental impact. It is important to choose the right mode of transportation for the product and think about in what shape, or type of packaging it should be transported.

*Figure: Some products can be transported in a disassembled state, or 'flat pack'. This saves space in transportation vehicles, so more products can be transported each time, reducing emissions.*

Mode of transportation 24



How might we..

## enable circularity through the transportation distance?

Transportation can have a high environmental impact. By reducing distances and investigating local opportunities, environmental impact of transportation can be lowered.

*Figure: The sale of regional products takes place, for example, via a farmers market or a subscription system. The advantages of regional agriculture are that animal welfare and landscape value are generally better guaranteed. It can also reduce energy consumption through lowered transport distances.*

Distance 25

How might we..

## enable circularity through the energy sources used?

(re)Production activities need energy input. To make sure that new circular supply chains do no have higher impact than linear supply chains, choosing the right energy source can be crucial

*Figure: At about 50 meters down, the earths temperature remains constant at around 10 degrees celsius. This constant temperature can be used to provide heating in the winter, and cooling in the summer.*

Type of energy 26

Which..

## business partners can you collaborate with?

Creating new partnerships in the supply chain or value network is essential to achieve circularity and close of resource loops. Can a new collaboration with a material supplier, transporter, maintenance specialist, reseller lead to new business ideas?

*Figure: Lendager architects collaborated with flooring producer Dinesen to design a kitchen out of residual wood from the production of wooden floors.*

Partners in supply chain or value network 27

How might we..

## incentivise circularity through the ownership of the product?

Determining who should be the owner of a solution, creates potential for circularity. If the manufacturer keeps ownership of a product, a stronger incentive is created to make long-lasting design, recirculate products and use materials effectively.

*Figure: Circos offers a subscription model for baby clothes, where clothes are returned and reused when outgrown. Circos keeps ownership of these clothes and optimizes the use of these resources.*

**Owner** **28**

How might we..

## incentivise circularity through determining the customer?

It is important to determine who is the customer in your scenario, as this can influence the design and promote a more effective use of resources. For example, is your customer the building owner, the housing association or the end-user?

*Figure: Laundry machines in shared laundry rooms are effectively used, the customer of these appliances are the building owners, the tenants only have access to them.*

**Customer** **29**

How might we..

## incentivize circularity by selecting the primary customer contact?

It is important to determine who is the primary customer contact in any scenario, as this can promote a more effective use of resources. For example, who is the primary customer for maintenance practices?

*Figure: Auping offers mattresses to hospitalityand consumers through a leasing contract. Primary contact is hospitality, as they have a maintenance contract included to wash/replace components for quality/hygiene reasons. Consumers pay a fixed rate per month and auping will take the mattres back for recycling at the end of life.*

**Primary contact customer** **30**

How might we..

## incentivize circularity through customer relations?

Defining the type of customer relation might be important for the succes of a circular solution. For example, does the solution include personal assistance, an automated helpdesk, or self-service?

*Figure: Forgo is hand soap purchased through an online store, they provide sachets with powder that can be mixed with water to create hand soap in the container of your choice. The customer relation is entirely online, there are no physical stores involved.*

**Kind of customer relationship** **31**

How might we..

**incentivize circularity by selecting the primary supply chain contact?**

It is important to determine who is the primary supply chain contact in any scenario, as this can influence the design and promote a more effective use of resources. For example, who should the user contact if a product breaks?

*Figure: Bundles offers coffee through a pay-per-cup subscription, including the machine, beans and maintenance. Although they are not the manufacturer of the machine, they are directly contact to requests repairs as a part of the subscription.*

**Primary supply chain contact** **32**

How might we..

**incentivise circularity through supply chain collaboration?**

Structuring collaboration between stakeholders e.g. through industry associations, co-creation or joint ventures, might lead to more effective use and recirculation of resources. Think about how such activities can take place.

*Figure: Kalundborg symbiosis is a partnership between eleven public and private companies, where the residue from one company becomes a resource at another.*

**Kind of collaboration** **33**

How might we..

**incentivise circularity through the cost proposition?**

Think about how the costs are divided in the context you're working with. Are the higest costs in manufacturing, installing or operational phase of your solution?

*Figure: Most environmental impact of a laundry machine is in the use phase. Homie let's the customer pay per wash, instead of owning the machine, incentivizing effective use of energy.*

**Cost proposition** **34**

How might we..

**incentivise circularity through financial arrangements?**

Different financial arrangements such as e.g. product-service systems (PSS), renting, leasing or pay-per-use, can provide a better service and customer experience while using resources more effectively.

*Figure: Rather than selling the actual lighting, Philips sells a promised level of illuminance as a service in a building according to their 'pay per lux' concept.*

**Financial arrangement** **35**

How might we..

**incentivize circularity through income division?**

How is the income that your circular solution generates divided amongst the involved parties, is there specific income per company? In 'mini' coalitions? Or is it divided over the value chain?

*Figure: Apple generates incomes from selling the Iphone, but to a limited extent from offering repairs. There are many dedicated repair shops that generate income from repairing iphones.*

**Income division** **36**

How might we..

**incentivise circularity through a product/service proposition?**

By proposing suitable services alongside a product and make them part of the solution, practices such as repair, maintenance and updates can be more easily provided.

*Figure: Ahrend offers furniture as a service, furniture pieces are equipped with a QR code to request maintenance and repairs.*

**Product / service proposition** **37**

How might we..

**Deliver value?**

Proposing a circular solution becomes more feasible and creates more market demand if it delivers additional or unique value compared to other available solutions.

*Figure: Gerrard street takes the hassle of broken headphones and cords away by providing a subscription-based modular headphone with included service, this delivers extra value for customers that want to have working headphones at all times.*

**Value delivery** **38**

How might we..

**Capture value?**

Think about the value you can capture for all the involved stakeholders of your solution. The solution might spark more interest and becomes more feasible if it captures value and interest for everyone involved.

*Figure: Palm Silage captures value for themselves, the municipality and the environment by transforming palm fronds that fall and end up all over cities to food for livestock.*

**Value capturing** **39**

Which..

## resources would be needed (to incentivise circularity)?

Think about the physical, intellectual, human and financial resources needed for your circular proposal. For example, storage facilities for material, or people that perform repairs.

*Figure: Ikea has a large number of stores in many countries in the world. At the store, customers can return used furniture and receive coupons in exchange. These pieces of furniture are sold in a special second-hand section of the store.*

**Key resources per partner 40**

Which..

## sale and (re)loop channels might incentivise circularity?

Think about the type of channels that can be utilized to reach out to users, and set up a structure for (re) looping products, parts and materials. For example, can you use digital channels such as a webshop or social media to provide information and logistics.

*Figure: Patagonia products can be exchanged and returned in their store or shipped back for free. If a product needs repair, they offer repair guides online or the product can be brought to the store for repairs.*

**Sale and (re)loop channels 41**

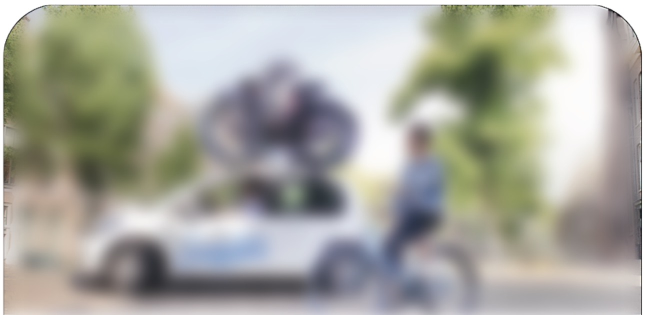
How might we..

## incentivise circularity with facilities for take back?

Through take-back systems, key resources can be returned and re-looped in the system. This helps companies retrieve valuable and finite materials and can support users with a clear and easy way to return materials.

*Figure: Used printer cartridges from HP can be returned for recycling, they offer consumers labels on their website to return cartridges for free through the post.*

**Facilities for take back 42**



Which..

## factors impact the adoption of a circular business model?

What are important factors for the adoption of your circular proposal? For example: Is it driven by policy and legislation? Is there customer acceptance and demand? Does it require trust between supply chain partners?

*Figure: Some people rather have access to a bike or car, than own one. Hence, bike subscriptions like Swapfiets are becoming increasingly more popular.*

**Circular business model adoption factors 43**

## Cards for Circularity (CfC) workshop manual

This section describes a procedure for organising a workshop with the CfC. The manual is provided ahead of the workshop and briefly introduces the CE concept as well as the different steps in the workshop and the functioning of the web version of the CfC.

# Cards for Circularity

workshop manual

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# Index

# General

## Goal

Cards for circularity is a card-based tool to support your circular design thinking. During this workshop, you will be divided in groups and as a group you will develop ideas and a concept for a circular product/building solution based on a given case.

## Means

You will make use of a selection of cards from the Cards for Circularity tool, which aims to support you in the design process. Each group needs at least 1 computer to use the web-based app, having more computers can be convenient. Use the web-based app which you can find here (mobile phone works as well):

www.cardsforcircularity.com

Each group will be supplied with paper and pen. Feel free to be creative and visualize ideas as much as possible (paper sketching, mind maps, digital sketching/modelling, miroboard, collage with inspirational images).

## Teams and assignment

This workshop is conducted physically. **Introduction, explanation of the workshop phases and debriefing will be done with all participants**, while the **phases of the workshop itself are done in smaller groups of maximum 5 people**. The assignment is performed as a team, you will receive a number and find your team at the table with corresponding number. Each team will develop ideas for a certain case, the cases will be provided by the workshop leaders and a detailed case description can be found in a separate document.

# Introduction

You are about to use Cards for Circularity to develop a circular solution for a case. But what is circularity? And what is the circular economy?

The circular economy is an alternative to our current (linear) economy. In our linear economy, we take resources, make products, use the products, and then dispose of them. In a circular economy, disposal is replaced by re-loops such as reuse, repair, refurbishment and recycling for technical materials, and biological materials are returned into the biosphere through biodegradation or composting. Figure 1 shows the 'butterfly' model of the circular economy, with all its re-loop processes.

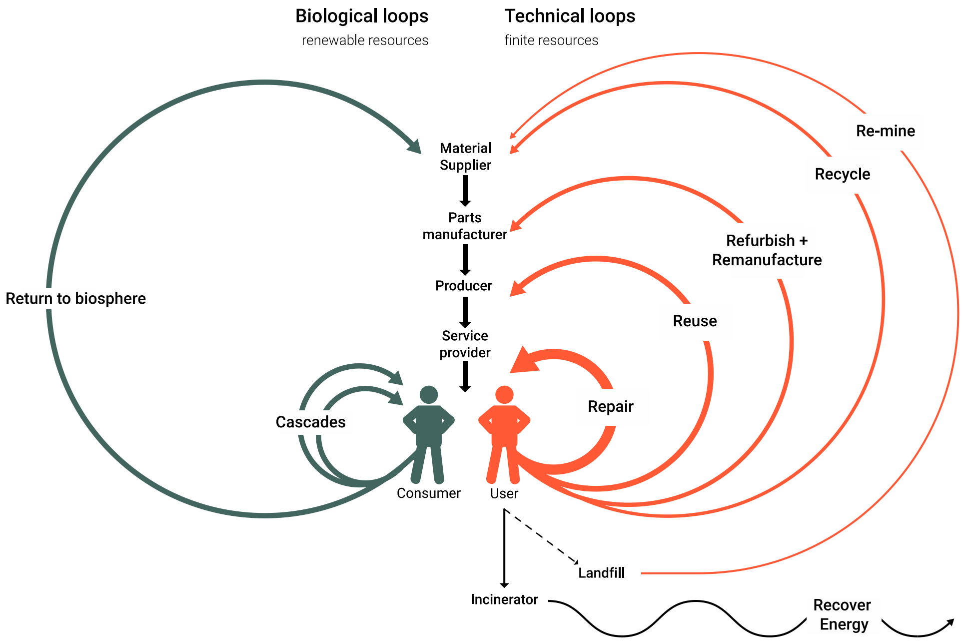



Figure 1. CE system diagram, adapted from The Ellen MacArthur Foundation (2017) and Reike, Vermeulen, & Witjes (2018).

According to Geissdoerfer et al. (2017, p. 759), the circular economy is "a regenerative system in which resource input and waste, emission, and energy leakage are minimized by slowing, narrowing, and closing material and energy loops". By narrowing loops, we mean to use less resources, slowing means to use resources longer, and closing loops means to recycle or bring back into the biosphere.
When we talk about circularity, we are talking about how well something fits the circular economy.

Narrowing Loops

Use less resources

Slowing Loops

Use resources longer

Closing Loops

Recycle or bring back into the biosphere

# Cards

Cards for circularity is a card-based tool to support your circular design thinking. It includes different strategies for achieving circularity in a design and shows some illustrative examples. Because a well-functioning circular product rests on three legs like a stool, if one of these legs is missing the stool falls over and the product is likely to not work for the circular economy. Therefore, the cards are divided into three different categories:

**Technical Model**

The Technical Model cards refer to the physical design of the product. This refers to aspects such as shape, construction and materialization.

Cards in this category help **make circular use physically possible**.

**Business Model**

The Business Model cards refer to aspects regarding finance and economic feasibility.

Cards in this category help **incentivize circular use**.

**Industrial Model**

The Industrial Model cards refer to the composition of the supply chain.

Cards in this category help **facilitate circular use**

# Workshop

The workshop itself is divided into a number of phases: Orientation (Phase 1), Selection (Phase 2), Ideation (Phase 3) and Finalization (Phase 4). You will have a total of 2 hours and 15 minutes for the entire workshop. On canvas you will find a separate document with a detailed schedule for the entire afternoon. On the following pages, each of the phases will be shortly described and illustrated. At the bottom of each page you can find some tips that might make things easier. At the top of each page you will find the recommended time for each phase.

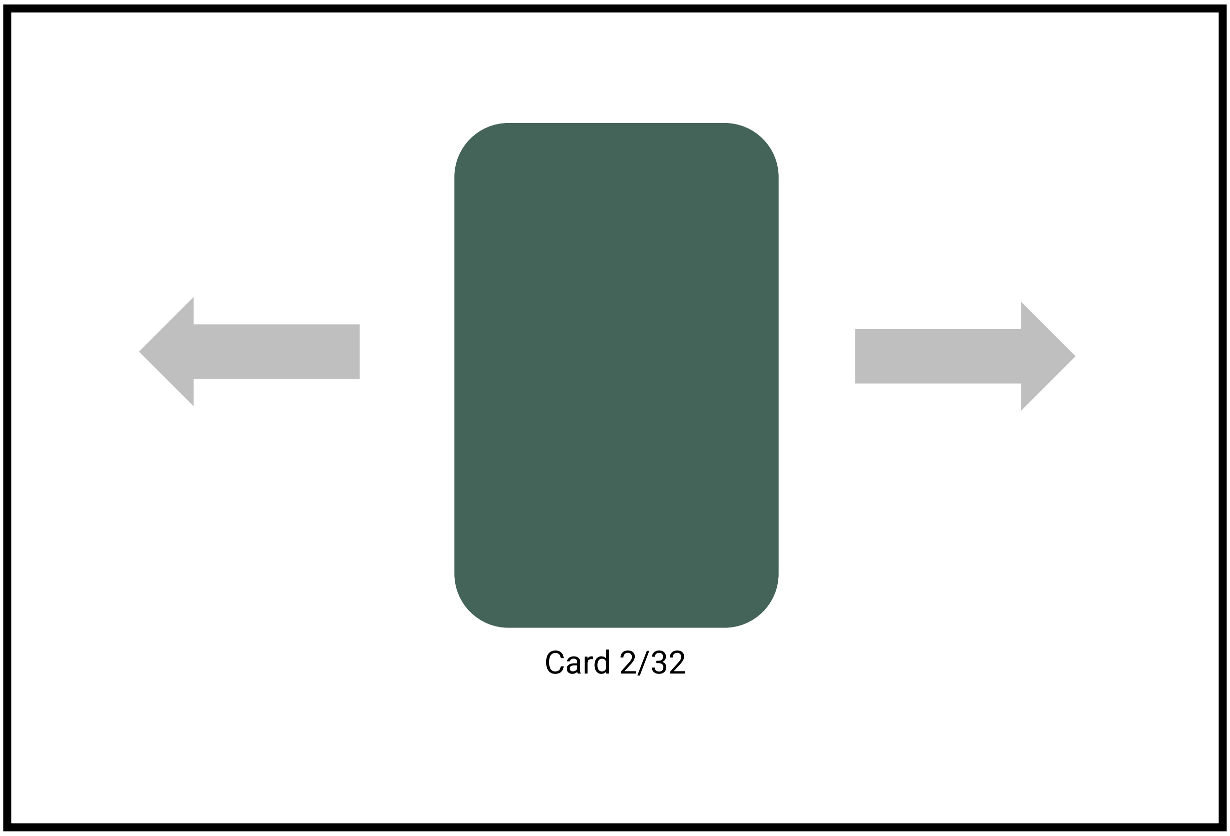
## Phase 1: Orientation

(15 minutes)

In this phase you will get to know the cards used in Cards for Circularity. All the cards can be found In Phase 1 of the webtool, that looks like the image below. There are a lot of cards, read through them as a team and discuss them shortly. Multiple computers/devices can be optimal for a better reading experience amongst your team members. Reviewing the cards individually is also possible.

*Make sure that every team member has the tool in their own web browser.*

*Webtool layout:*

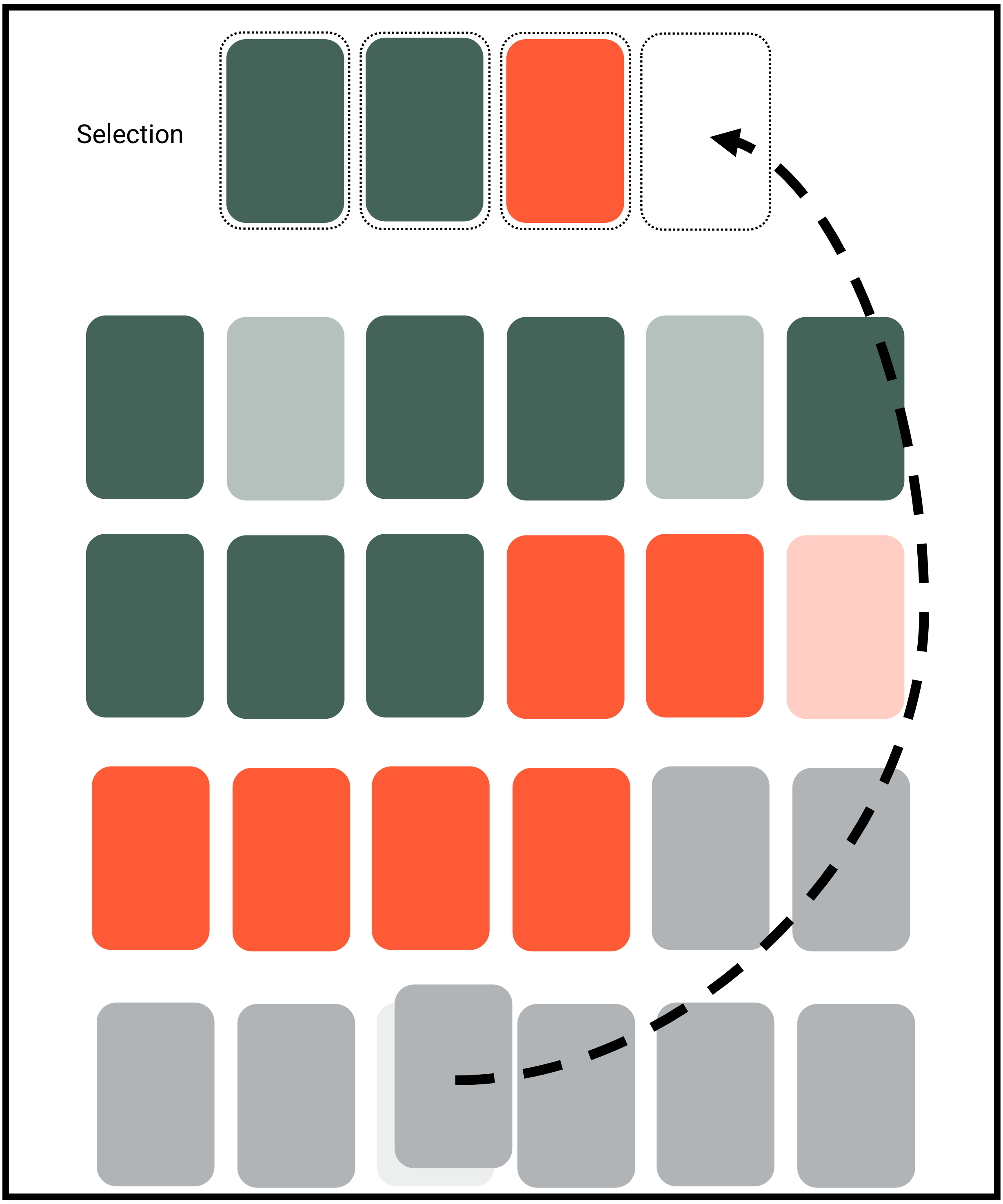



*Tip: If possible, make notes of which cards could be beneficial for your goal (to develop a circular product/service for your specific case), this will make the next phase easier.*

**Phase 2: Selection**
(30 minutes)

In this phase, you will select the cards you want to use for your solution to the case. Discuss the cards you have pre-selected in the previous phase and pick 4 cards out of the total grid of cards that can be seen in Phase 2 of the webtool.

*Webtool layout:*




*Note: you are free to select however many cards per type of cards you want. For example, you can select 4 technical model cards, but also a combination of technical, industrial and business model cards.*

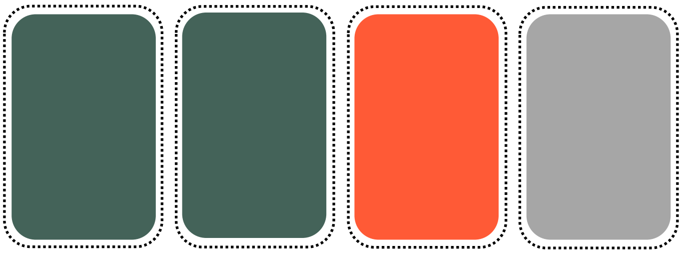
## Phase 3: Ideation

(60 minutes)

Now you are going to generate ideas. Based on the cards you have selected, try to come up with ideas on how you can use the strategies on the cards for your card. Think about one card specifically or see if you can combine cards to generate an idea. The ideas can be in different directions according to the cards, you can do a physical design of the product, create a new business model or think on an industrial level about partnerships/transportation etc. Discuss ideas, go wide, be creative!

Based on all the ideas generated, discuss with the group and select one direction to continue with. Combine ideas into one concept if possible. Try to evaluate which idea has the most potential to support circularity.

Selection



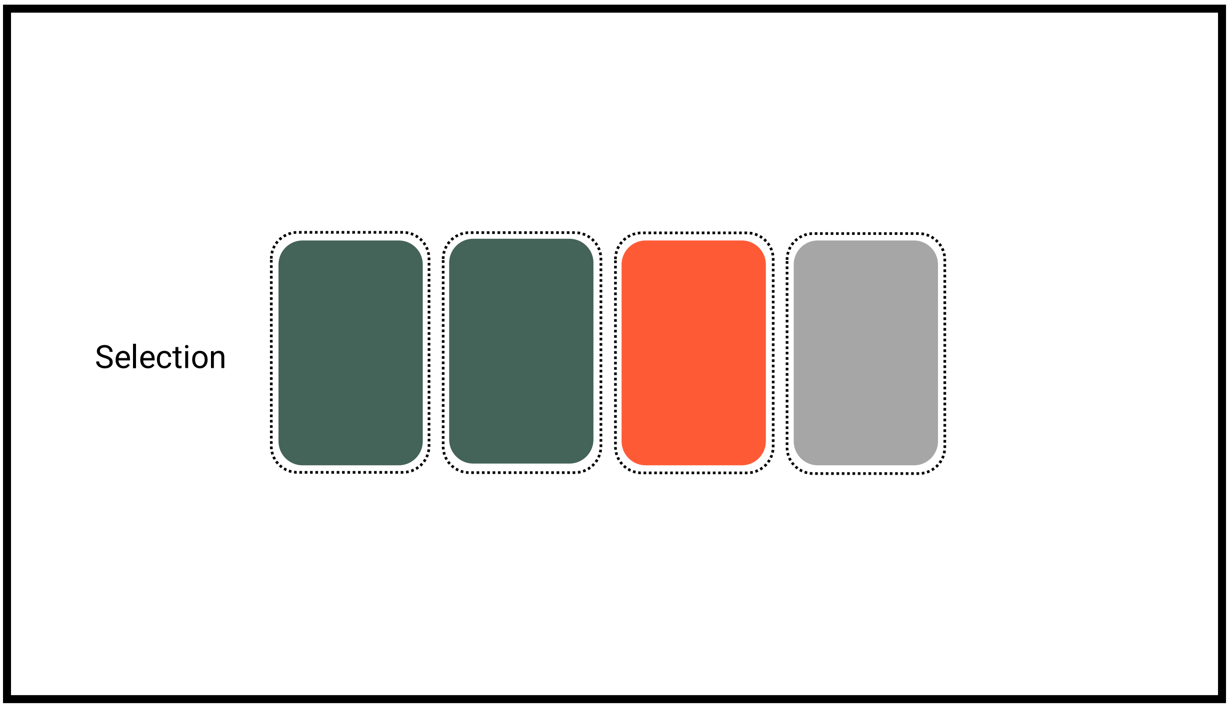
## Phase 4: Finalization

(30 minutes)

Try to summarize your concept on one paper using images and text, feel free to be creative. If you are working digitally, feel free to prepare your final sketches and presentation on your computer.

Save a screenshot of the selected cards from the webtool on your computer as shown below.

*Webtool layout:*



# Sources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