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DOI
10.3390/su12041561

Publication date
2020

Document Version
Final published version

Published in
Sustainability

Citation (APA)
Sumter, D., de Koning, J., Bakker, C., & Balkenende, R. (2020). Circular economy competencies for design. *Sustainability*, *12*(4), 1-16. https://doi.org/10.3390/su12041561

sustainability

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Circular Economy Competencies for Design

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Received: 13 January 2020; Accepted: 17 February 2020; Published: 19 February 2020

Abstract: This study addresses what competencies (knowledge, skills, and attitudes) designers need in order to successfully design products and services for a circular economy. Existing literature, though sparse, has identified a number of circular economy competencies for design. Yet, a coherent overview is lacking. To complement the competencies found in the literature with insights from practice, we conducted 18 semi-structured interviews with design professionals. Our study identifies seven circular economy competencies for design: (1) Circular Impact Assessment, (2) Design for Recovery, (3) Design for Multiple Use Cycles, (4) Circular Business Models, (5) Circular User Engagement, (6) Circular Economy Collaboration, and (7) Circular Economy Communication. We used a general sustainability competencies framework to categorize our findings. Interestingly, we did not find evidence of the Systems Thinking competency in practice, although in the literature it is mentioned as a relevant competency for design for a circular economy. In addition, we found that methods and tools are still largely lacking or in a premature stage of development. We conclude that design for a circular economy can be seen as an upcoming, independent field within the sustainability domain, and that requires a specific set of competencies, methods, and tools. Our overview of circular economy competencies for design can guide the development of relevant methods and tools, circular economy-based design curricula, and training programs in the future.

Keywords: design education; competencies; circular economy; product design; sustainability; circular consumption

1. Introduction

It has been recognized that the linear throughput of materials and energy, which is focused on resource extraction, production, use, and discarding of products (i.e., the so-called take–make–use–waste model), challenges sustainable development [1]. The circular economy, which is described by the Ellen MacArthur Foundation as restorative and regenerative by design [2], offers an alternative. The aim of design for a circular economy is to maintain product integrity over multiple use cycles (for instance through repair, refurbishment, and remanufacturing), and to focus on closing loops (through recycling), while at the same time building economically viable product–service systems [3].

The European Commission emphasizes the role of design in the EU action plan for the circular economy: "better design can make products more durable or easier to repair, upgrade or remanufacture" [4] (p.7). The overarching aim of design for a circular economy is to contribute to sustainability [5]. It can be seen as one of the approaches in the design for sustainability field. Other approaches within the design for sustainability field include ecodesign [6], nature inspired design [7], sustainable product–service systems [8], design for low resource settings (also knowns as design for the base of the pyramid) [9,10], design for social innovation [11,12], and transition design [13].

Similar to the other design for sustainability approaches, design for a circular economy has its own specific procedures and concepts. The concept of the circular economy has gained traction

because it is considered operationalizable [14–16]. The emphasis on high value, high-quality cycling of material resources is novel. In addition, it easily connects sustainable production and consumption, advocated by means of sharing and reuse [1]. Value recovery strategies, such as repair, refurbishment, and remanufacturing, are used in the context of circular business models, in which for instance ownership of products is transferred from the user to the company (e.g., access or performance-based models). This results in new relationships between companies and customers, who now become temporary users of products [17].

These novel approaches for a circular economy also require the development of new competencies and knowledge accordingly [18]. While the amount of literature on the circular economy is growing, there is limited academic literature that explores the competencies needed and the consequences for design education or practice. Hence, the main research question of this study is as follows: What competencies do designers need in order to successfully design products and services for a circular economy? We follow the definition of a competency as "a functionally linked complex set of knowledge, skills, and attitudes that enable successful task performance and problem solving" [19].

In this paper we first present a generic framework of sustainability competencies, based on Wiek et al. [19]. Secondly, we discuss the circular economy competencies for design found in the literature according to this general framework. Thirdly, we present seven circular economy competencies for design, based on the results of 18 semi-structured interviews. Lastly, we present a coherent overview of circular economy competencies for design, using a general sustainability framework.

2. Background

In this section we present the literature on generic sustainability competencies together with literature on circular economy competencies for design. The associated concepts and methods, if mentioned in the literature, are also described.

2.1. Sustainability and Design for Circular Economy Competencies

Literature agrees on five key sustainability competencies needed to contribute to sustainable development. These are (1) systems thinking, (2) anticipatory, (3) normative, (4) strategic, and (5) interpersonal competencies [19]. These five key competencies are often reflected in overviews in the general sustainability literature [20–22]. They are listed by UNESCO [23] as essential for achieving the Sustainable Development Goals (SDGs). These five competencies also serve as a reference framework of a "distinct and recognizable qualifications profile for research and teaching." [19] (p. 211). Important to note is that solving sustainability problems requires the use of all competencies; they should not be viewed or used in isolation [19]. In the following sections we explain what these generic sustainability competencies entail and how they can be understood in the context of design for a circular economy. Table 1 gives an overview of the competencies.

2.1.1. Systems Thinking Competency

According to Wiek et al. [19], the Systems Thinking competency entails: "(. . .) the ability to collectively analyze complex systems across different domains (society, environment, economy, etc.) and across different scales (local to global) (. . .)" (p. 207). Systemic features, such as cascading effects, inertia, cause–effect chains, feedback loops, and tipping points, are essential concepts in systems thinking. This competency requires the use of participatory system approaches and tools that support modelling and system analysis [19] to respectively understand and analyze the sometimes complex connections and flows between different nodes in a system.

In the context of circular economy, literature suggests that design and engineering education needs to offer students new skills for the circular economy, such as systems thinking [2,24–26]. Systems thinking is seen as an enabler to "fully comprehend both the drivers behind the problems as well as the possible solution space" [26] (p.335). It is used to both analyze a system as well as identify possibilities to change a system to satisfy the needs of a specific group. While the literature acknowledges the

need for systems thinking in (design for) a circular economy, this does not go beyond a generic call for "more holistic thinking". Systems thinking methods that could be useful in the context of design for a circular economy are the Circularity Thinking method, which can help to explore the current system and possible future circular systems; the Circularity Compass, which can help to identify where waste is in the system; and the Circularity Grid [27], which can generate an understanding about the relationships between the parts in the system.

2.1.2. Anticipatory Competency

The anticipatory competency entails "the ability to collectively analyze, evaluate, and craft rich 'pictures' of the future related to sustainability issues and sustainability problem-solving frameworks" [19] (p. 209). This competency is linked to concepts like time, uncertainty, plausible futures, and risks. Methods related to this competency assist in looking towards and predicting the future.

In the context of design for a circular economy, literature mentions the ability to design for multiple use cycles [28,29]. We consider this an anticipatory competency as it requires designers to develop a design that is "futureproof" and can be used during multiple cycles. Den Hollander refers to this as "longitudinal value propositions" [3] (p.158) and "longitudinal business models" [3] (p. 160). This implies that during the design process the value propositions and business models for all future use cycles should be consciously designed. Some of the general anticipatory sustainability methods, such as visioning and back casting, will be useful for design for a circular economy, too. But, distinct circular anticipatory methods, which support the creation of longitudinal value propositions and product–service designs that can create value over multiple use cycles, will need to be developed. Distinct methods are also lacking for the creation of products with a fixed and pre-designed number of use cycles [30], after which these products are recovered and reused. An example of an anticipatory circular thinking method is the circular business model mapping tool [31]. It helps to visualize planning of the product life cycle and assess how the circular offering will change during each use cycle. Another potentially useful tool is the framework on material change [32]. It is meant to help designers understand material change over time. However, these methods are still at an early stage of development.

2.1.3. Normative Competency

The normative competency is "(. . .) the ability to collectively map, specify, apply, reconcile, and negotiate sustainability values, principles, goals, and targets" [19] (p. 209). Methods related to this competency are sustainability assessment methods such as life cycle assessment (LCA) [5], risk analyses, and methods that are connected to the anticipatory competency as well, such as back casting [19]. The normative competency is also about formulating sustainability principles, being able to understand and discuss the ethical side and considering concepts such as justice and fairness.

In the context of design for circular economy, literature mentions competencies related to estimating environmental impact over multiple use cycles [28,29]. Den Hollander et al. [33] mention that designers, when aiming to extend product lifetime, need to be able to assess the environmental consequences of their design interventions. This falls within the normative competency as the underlying ability to estimate environmental impact relates to making assessments about circular solutions. Yet, the difference with general sustainability is that the assessments are to be made on a systems level over multiple use cycles, including take back options (e.g., circular impact assessment). A second relevant competency in this respect is the ability of setting circular criteria [29] and using circularity indicators to determine the extent of circularity of current and future design projects. Useful methods within this context are (material) circularity indicators for products [34] and tools to estimate environmental impact of circular economy strategies [35]. Research suggests that, while the current circularity assessment tools can help to give an indication of the product performance in the context of

circularity, they do not reflect the complexity of the circular economy and guidance for designers is missing [36].

2.1.4. Strategic Competency

The strategic competency is "the ability to collectively design and implement interventions, transitions, and transformative governance strategies toward sustainability" [19] (p. 210). This competency is associated with high-level concepts such as transitions, governance, viability, success, and path dependencies [19]. It reflects the wider perspective of the sustainability field. Methods related to this competency are about creating change on and from a high level, and that help with planning and decision making as well as with organizational and behavioral change.

In the context of design for circular economy, literature mentions competencies related to concurrently developing circular business models and product designs [28]. Den Hollander et al. [33] also suggest that design for a circular economy requires that products and business models that can capture economic value over multiple use cycles are designed simultaneously. This competency can be categorized as a strategic competency in the framework of Wiek [19], as this reflects a need to think about the viability and scalability of the solution. A relevant tool for this competency is the circular business model canvas [37]. Competencies related to user engagement can also be gathered under the strategic competency [17] as user engagement is essential for successfully implementing a circular business model. Currently, consumer acceptance of product access versus ownership is still a challenge [38]. A stigma on "second-hand" products influences the consumer acceptance of "recovered products" by means of repair, refurbishment, or remanufacturing [39]. Hence, designers should consider the factors that influence user perception and acceptance of recovered products [40]. However, useful design methods are scarce.

2.1.5. Interpersonal Competency

The interpersonal competency encompasses "the ability to facilitate collaborative and participatory problem solving, while ensuring a respective and empathetic exchange of perspectives and actions and dealing with conflict resolution" [19] (p. 211). This competency is associated with concepts such as leadership, success in teams, and the dynamics of collaboration. Methods related to the interpersonal competency are about teamwork and participation.

In the context of design for circular economy, the literature mentions the need to facilitate collaboration between stakeholders in an entire value chain or value network [28,41]. This can be categorized as an interpersonal competency as it reflects the need to identify and form partnerships. Methods that could aid in this process are, for example, stakeholder mapping, which can be used to create an overview of who should be involved and what the stakes and relationships are. Geissdoerfer et al. [42] used the method of value mapping to inter alia harmonize stakeholder interest. Last, literature talks about co-creation, mainly in the form of innovation and living labs, as a method to stimulate collaboration between stakeholders for a circular economy [43,44]. Yet, these experimentation spaces have not yet been around for long, so it is unclear what the outcomes will be in long term.

An essential element when it comes to collaboration is communication. In the context of design for circular economy, we previously identified competencies such as "circular economy understanding" and "circular economy story telling" [29] (p. 3). However, due to the newness of the field and the lack of formal circular economy vocabulary there is conceptual and terminological confusion among design researchers. Circular economy has even been called a "catch-all philosophy" [26] for its lack of guiding language. This is an obstacle for designers and others to talk about circular solutions.

Table 1. Sustainability and circular economy competencies for design (literature).

Competencies	Sustainability	Design for Circular Economy	Circular Economy Concepts and Methods
Systems thinking competency	"(. . .) the ability to collectively analyze complex systems across different domains (society, environment, economy, etc.) and across different scales (local to global) (. . .)." [19] (p. 207)	• Systems thinking [2,24,25] and holistic thinking [26]	Concepts • Restorative and regenerative by design [2] • Circularity Thinking [27] Methods • Circularity Compass and Circularity Grid [27]
Anticipatory competency	"the ability to collectively analyze, evaluate, and craft rich 'pictures' of the future related to sustainability issues and sustainability problem-solving frameworks" [19] (p. 209)	• Considering product wear over time during the design process [17] • "Designing for multiple use cycles" [29] (p. 3) • "Anticipate how the circular offering will evolve over multiple life cycles" [28] (p. 13)	Concepts • Multiple use cycles; longitudinal value propositions [3] Methods • Circular business model mapping tool [31] • Framework on material change [32]
Normative competency	"the ability to collectively map, specify, apply, reconcile, and negotiate sustainability values, principles, goals, and targets " [19] (p. 209)	• "Setting circular criteria" [29] (p.3) • "Assessing circular solutions" [29] (p. 3) • "Estimate the environmental impact on a system level over multiple life cycles" [28] (p. 12) • Consider the consequences on environmental impact of design interventions focused on product lifetime extensions [33]	Concepts • Measuring circularity; Circular impact assessment Methods • Circularity indicators [34] • Tool to measure impact of circular strategies [35]
Strategic competency	"the ability to collectively design and implement interventions, transitions, and transformative governance strategies toward sustainability." [19] (p. 210)	• Considering the user experience, expectation and perception of value during (service) design process [17] • Considering circular logistics and distribution process [17] • "Connecting reverse logistics with users" [29] (p. 3) • Develop the circular business model in conjunction with the product's design [28,33]	Concepts • Circular business models, access-based models; performance-based models; • User experience Methods • Circular business model canvas [37] • No specific design methods for understanding user engagement for circular business models identified
Interpersonal competency	"the ability to facilitate collaborative and participatory problem solving, while ensuring a respective and empathetic exchange of perspectives and actions and dealing with conflict resolution." [19] (p. 211)	• "Circular economy understanding" [29] (p. 3) • "Circular economy storytelling" [29] (p. 3) • "Facilitate collaboration between internal and external stakeholders who play a role in operationalizing a circular business model" [28] (p. 12)	Concepts • Collaboration across value networks [41] • Circular economy vocabulary [26,29] Methods • Value mapping [42]; • Co-creation in experimentation labs [43,44] • No specific tools for circular economy communication

2.2. Sustainability and Design for Circular Economy Competencies: An Overview

Table 1 gives a summary of the just discussed general sustainability and circular economy competencies for design, as well as the relevant methods and concept listed within the literature. Categorizing the circular economy competencies for design listed in the literature, using the sustainability framework (based on Wiek et al. [19]), showed us that in general there is an overlap between the circular economy competencies for design and the sustainability competencies. Yet, in the specifics there are differences. The newness of the circular economy field is reflected by the limited number of methods available and the premature development state they are in. The following sections present our study that evaluates and (potentially) expands the list of competencies through a practice-based inquiry. The goal is to come to a coherent list of competencies that designers need to successfully design products and services for a circular economy.

3. Research Method

Learning in-depth from real life cases is an effective method to obtain insights about emerging fields such as design for a circular economy. To evaluate the listed competencies found in the literature with empirical evidence, we conducted 18 interviews with design practitioners. The participants, who all have a design background and/or are working in the role of industrial designer, had experience developing circular solutions in practice.

3.1. Data Collection

We conducted a total of 18 interviews. The interviews were conducted face-to-face (10) and via Skype (Skype Limited, Palo Alto, CA, USA) (8) and took place between April 2018 and November 2019. They lasted 40 to 120 min. Interview number 14 was conducted with two participants simultaneously as they both participated in the same project. A standardized semi-structured interview [45] was used to ensure consistency between the interviews. We queried the designers about their experience developing specific circular solutions. Table 2 gives an overview of sample questions per topic discussed during the interviews. Depending on the native language of the respondents, interviews were conducted in either Dutch or English. The interviews were recorded and transcribed verbatim. During the first round of coding, those interviews that were conducted in Dutch, were translated to idiomatic written English.

Table 2. Interview topics and sample questions.

Topics	Sample Questions
Defining circular economy	How would you characterize the circular economy?
Circular solution	Please elaborate on the circular solution that you have been working on? What did you do in practice/concretely to develop the circular solution?
Challenges	What hindered you in this process? How did the hurdles prevent you from completing the case?
Support	Which methods/tools did you use in this design process? When? What were you missing that could have helped you in terms of mindsets, knowledge?
Vision on the role of designers	How do you see the role of designers in (transition towards) a circular economy?

3.2. Interviewees Profile and Selection

To acquire a broad and representative perspective on circular design competencies, we interviewed designers working in differently sized companies (ranging from start-ups to multinational companies) on a variety of circular design offerings. Nine designers were recruited based on their participation in CIRCO workshops, a Dutch government funded program for companies working on circular offerings. Further, we approached designers from our circular economy network and used the snowballing technique to get in touch with additional interviewees. The designers all had been actively involved in developing circular offerings. This ensured that we could query them about real life cases and experiences instead of hypothetical futures. Table 3 gives an overview of the interviewees, a description of their job title, and the circular offering they developed.

Table 3. Participants data. Company size listed, whereby Micro < 10 employees, Small = 10–50 employees, Medium = 51–250 employees, and Large > 250 employees.

Participant Number	Job Title	Circular Value Proposition	Company Size
1.	Cofounder	Electronic devices as a service	Micro
2.	Managing Designer	Concept proposal for circular street furniture	Small
3.	Design Engineer	House style of electronic devices as a service	Micro
4.	Senior Industrial Designer	Reusable product packaging	Small
5.	(Product Design) Researcher	Circular product and value proposition design in the mattress industry	Medium
6.	Founder/Owner	Design of circular interior and furniture	Micro
7	Operational Manager	Waste repurposing solutions	Micro
8.	Resource Efficiency Manager	Designing modular electronic devices and considering access-based models	Medium
9	Sustainable and Circular Product Designer	Sustainable packaging using mono-material	Micro
10.	Founder/Owner	Mobility solution using bio-based materials and access-based models	Micro
11.	Founder/Owner	Modular office supply	Micro
12.	Game Designer & Consultant	Designing and manufacturing a strategy game about material resource-efficiency	Micro
13.	Senior Design Strategist	Circular design propositions within a corporate that manufactures household appliances & healthcare products	Large
14.	Design Director (a) Design Engineer (b)	Circular reusable packaging system	Medium
15.	Senior Director, Head of Design	Circular propositions in electronics corporate business	Large
16.	Industrial Designer	Assessing and improving repairability of vacuum cleaners sold by a corporate	Large
17.	Industrial Designer	Modular product-service system for personal care	*Independent project*[1]
18.	Concept Design Manager	Modular train interior	Large

[1] Participant 17 independently conceptualized and prototyped a circular value proposition as part of his graduation assignment.

3.3. Data Analysis

To ensure qualitative rigor during the analysis of the data we employed the Gioia methodology [46]. Transcriptions were coded and analyzed using qualitative data analysis program NVivo 12 (QSR International, Melbourne, Australia). A total of 384 quotes were categorized in 27 first-order themes and 7 second-order themes, using this tool. Table 4 lists the 27 first-order themes and the 7 second-order themes.

Table 4. Coding scheme.

First Order Themes	Second Order Themes
• Investigating materials sourcing and material performance in time • Estimating and comparing environmental impact of solutions over multiple use cycles	Circular Impact Assessment
• Considering alternative recovery strategy • Designing the supportive infrastructure relevant for recovery • Collecting information of product in market • Tracking technological trend development for recovery strategy • Determining implication for design embodiment based on recovery strategies	Design for Recovery
• Categorizing components by lifetime • Assessing product use cycle based on fashion trends • Planning exchange of component • Using visualization as tool to get an overview of the value chain	Designing for Multiple Use Cycles
• Considering the business case during the product's design • Determining prices for services and implication of new financial structure • Testing and piloting new initiatives • Considering the consequences of alternative business cases	Circular Business Model
• Investigating customer awareness and perception of ownership vs. access • Designing customer interaction with product • Collecting and sharing information about value chain • Tailoring service to customer context during use • Creating attractive incentives for customers to give back products	Circular User Engagement
• Identifying partners to share knowledge and activities to operationalize value proposition • Collecting and sharing information about value chain • Assessing consequences of changing stakeholder configuration • Using design as boundary object to collect stakeholder feedback	Circular Economy Collaboration
• Getting circular buy-in • Creating shared understanding • Facilitating empathetic conversations between stakeholders	Circular Economy Communication

In the first step of coding we stayed close to the terms used by the interviewees and came to 27 first-order themes via an inductive approach. We iterated several times during this process, looking for similarities and differences between the initial themes and clustering these. In the process we labelled the first-order themes with so-called phrasal descriptors [46] (e.g., getting circular buy in, categorizing components by lifetime, and considering alternative recovery strategies). In the second round of coding we categorized the 27 first-order themes into overarching themes using relevant concepts from literature listed in Table 1. For example, first-order themes related to impact assessment were categorized in a second-order theme about circular impact assessment. During the coding process

we shared a set of transcripts between the authors of this paper for independent clustering, to ensure intercoder reliability. The final coding resulted in 7 second-order themes. The final descriptions of these 7 themes came about from discussions between all the authors. Finally, based on these themes, we formulated seven circular economy competencies for design.

4. Results

In this section, we describe the main insights that we derived from the study. The interviews enabled us to identify seven circular economy competencies for design: (1) Circular Impact Assessment, (2) Design for Recovery, (3) Design for Multiple Use Cycles, (4) Circular Business Models, (5) Circular User Engagement, (6) Circular Economy Collaboration, and (7) Circular Economy Communication.

4.1. Circular Impact Assessment

Seventeen out of the 18 interviewees referred to topics related to circular impact assessment. First of all, the interviewees mentioned the impact assessment of alternative circular strategies and materials. They used fast-track life cycle assessments instead of a full life cycle assessment (LCA) as time was their biggest constraint. Some participants felt the tools fell short when they tried to measure environmental impact over multiple use cycles. The large number of assumptions that are needed to build an LCA was seen as the reason that the final outcome cannot not be used to support decision-making. In addition, the interviewees mentioned that the disparity between theory and practice affects decision-making as well. Participant 14a: "Plastic can be recycled well in theory, but in practice this appears to be different. You have to weigh those things and that is complex". Another element mentioned here were the circular economy indicators that could help designers determine the circularity of the value proposition they were developing. Participant 13 noted that traditional design requirements have clear indicators that show whether "you pass or fail" and he mentioned: "What I think designers do not learn (. . .) is how to assess whether or not they are (on the right path to going) circular. They often have a subjective ability to rationalize if they have made progress." Based on the findings, we formulate the following competency:

- Circular Impact Assessment: Estimating the environmental impact of circular offerings on a system level over multiple use cycles to support decision-making during the design process.

4.2. Design for Recovery

Sixteen out of 18 designers referred to recovery strategies (i.e., strategies, such as repair, refurbishing and remanufacturing, meant to recover functionality and value in between use cycles and at the end of product life). Designing circular value propositions required the designers to consider recovery strategies and their consequences on the product and service–system design. Participant 3: "Your responsibility as a (supplier) of the product does not stop after sales. (. . .) You have to keep that in mind as a designer of the product". Participant 9 realized that next to developing the service she had to design a supportive infrastructure that would enable maintenance activities during use and take back of products: "Even if I am starting to sell a refillable bottle, there is not much opportunity for the consumer to refill". Further, the choice for a recovery strategy influences how the product will be designed. The interviewees realized that collecting information about products in use (e.g., where products are and in what state) could help them improve their recovery strategies and associated services. Participant 1, for instance, collected feedback about the rate of failure of certain components, both to improve the service as well as to improve the design of the next product. Participant 6 mentioned that collecting information about the state of their street furniture could help create an overview of where products are in the market. Lastly, some designers mentioned that there should be ways to estimate the remaining useful product "lifetime" upon takeback after use. Participant 8: "So, imagine you are in a contract for a service proposition, and you use your device with one battery for half a year. (. . .) I have no way to

know how you have used that battery, so I do not know what is the health of that battery. (. . .) There is no fast method to test that." Hence, we formulated the following competency:

- Design for Recovery: Incorporating recovery strategies during the design process while taking into account multiple use cycles.

4.3. Design for Multiple Use Cycles

Nine out of 18 designers also referred to how designing for multiple use cycles is different from their current way of designing. Design for multiple use cycles and design for recovery are highly related: Designing for multiple use cycles automatically implies considering recovery strategies, such as refurbishment, and remanufacturing, and how to implement these strategies in the design process.

The main differences with traditional design practice that surfaced from the interviews were thinking in terms of use cycles (e.g., knowing how the products and components will evolve during subsequent use cycles and how materials degrade over time) and considering the sourcing of materials (e.g., which materials are used in the product and where do they originate from). Thinking about multiple use cycles meant that designers had to determine to what extent future trends would impact the design of the current product. Participant 1: "So, you can easily do ten or fifteen years with the same headphone. Yet, the consumer wants something different. He wants to buy a new headphone every two or three years". This trend sensitivity also impacted the planning of introducing future products and accessories, both horizontally (e.g., product lines) and vertically (e.g., product generations). Participant 18 mentioned that even though designing a modular train interior could support different prolonged use cycles, planning was required as to when to change the sitting configuration. Another challenging factor was the lack of knowledge regarding the environmental impact of different materials when use was prolonged. Participant 2: "I think, you have to understand what the material does, really understand the material. So, how does it look when it is fresh (a virgin material), which aspects can you encounter, where does it come from, how do you collect it, what is the source material?" Hence, we formulated the following competency:

- Design for Multiple Use Cycles: Foreseeing the consequences of prolonged use and multiple use cycles.

4.4. Circular Business Models

Fifteen out of 18 designers mentioned business models during the interviews. Some of them mentioned that developing a circular solution entailed developing both the physical product, intangible service, and the business model. Participant 8: "You really need to think big and think not only (about) the physical thing but design the service in a way. Design the infrastructure.", and Participant 11 mentioned that more knowledge of the business model is required during the design of products. This included considering setting up and managing partnerships, reverse logistics, revenues and cost streams, and pricing of spare parts. Participant 3 noted: "It has become clear to me how important the link is between the business aspect and the design. That the (product) design, is only a part of the challenge (. . .). It also has a lot to do with how your income and expenses, your revenue streams, are structured." Some participants were not sure how to determine the financial and system consequences of switching from a linear to a circular business model. Participant 8 mentioned: "We made parts really cheap because we wanted to enable repairability so that people can just buy them for repair but that (. . .) (made it) really difficult to make any take-back program for them because there is no money to get back from those parts". Similarly, Participant 6 did not know yet what prices and conditions to set for the service part of a leasing concept that he was developing around a furniture concept, which included placing the product, maintenance during use and removal of the at the end of use. In general, designing circular solutions seems to require a level of business knowledge. We formulated the following competency:

- Circular Business Models: Concurrently developing the circular product, service, and business model.

4.5. Circular User Engagement

Twelve out of 18 designers referred to user engagement as important for circular offerings. One aspect was understanding why people bought into access-based models (e.g., what would be the benefits for the customers to lease a certain product). Participant 1: "because he [the customer] pays per month, (. . .) but he can also buy it, so what is the added value?" Participants also addressed the user-product interaction during and after the use of products. Participant 14b mentioned: "you need an active system to motivate people to (return products)". Participants 1, 8, and 17 explained that by applying modular design they supported the user to easily repair and upgrade certain components. In addition, the way the service was set up seemed to influence whether users bought into access-based models. Participant 1 mentioned: "I think the amount of days in which you sent a new part to the client is really important for your service." Participant 14a mentioned that it was important to develop an active system that motives users to return products. This was a new topic to consider during product design as this has not been part of business as usual were products are being made for one-time sales. Hence, we formulated the following competency:

- Circular User Engagement: Engaging users in the use and the (end-of-use) return of products.

4.6. Circular Economy Collaboration

Fourteen out of 18 designers talked about the importance of collaboration, for instance as a way to create shared value. Collaborating with new external partners was found to result in new ways of looking at challenges, new goals being set, and knowledge gained. In addition, participants saw both more internal and external collaboration as the way to operationalize circular offerings. Participant 11 talked about how going circular meant that she would need more information about the value chain and the materials, which she could obtain via intensified collaboration with suppliers. Instead of only requiring certain specifications from materials, some participants involved the suppliers in the design process. Yet, not all participants had experience working with their suppliers. Participant 13: "I have never really even entered a workshop together with a supplier to figure out how to come up with an offer". Participant 5: "It is going to be more and more important, to share your problems with your partners and together solve it, because we are not chemical specialists, we really need partners to help solve it". Designing for a circular economy requires the shared creation of value. Participant 15 mentioned that existing partnerships and contracts formed a challenge for creating new connections (e.g., convincing existing partners to change their roles or welcoming new participants in the value network). Based on this we formulated the following competency:

- Circular Economy Collaboration: Identifying, mapping, facilitating, and managing the collaboration between external stakeholders in operationalizing a circular business model.

4.7. Circular Economy Communication

Thirteen out of 18 designers referred to communicating internally and externally about circular solutions. Some participants faced problems related to external communication about the circularity of, for example, materials. Some experienced what Participant 13 called "the Tower of Babel problem with the circular economy" when they communicate about the topic internally. This was seen as a challenge for collaboration on circular initiatives. Participant 16 mentioned that when he discussed product reparability with the engineers he was working with, these engineers associated repairability with product modularity. Yet, his intentions were to improve the repairability of household appliances by making critical components easier to reach, which can be done in other ways than through modular designs. The plurality of interpretations of the circular economy made it difficult to get circular buy-in from people within the organization, suggesting that communication problems affected collaboration. In order to collaborate designers needed to get a circular buy in and create a shared understanding with both internal and external partners. This reflects that there is a strong link between

Circular Economy Collaboration and Circular Economy Communication. Hence, we formulated the following competency:

- Circular Economy Communication: Telling coherent stories about the circular offerings.

5. Discussion

The main scientific contribution of this study is the coherent and interlinked set of circular economy competencies relevant for designers. We ensured embedding in existing knowledge, by relating the competencies for design for circular economy to the generic sustainability competencies framework developed by Wiek et al. [19]. In this section we reflect on the circular economy competencies for design as found in our empirical study.

The competencies Designing for Multiple Use cycles and Designing for Recovery can be categorized as anticipatory competencies as they require designers to envision prolonged use of products. In comparison with other design for sustainability approaches, such as eco-design, design for a circular economy puts more emphasis on multiple use cycles. When designing circular propositions in practice, designers need to be able to envision and make prediction about what prolonged use will look like and make design decision based on these predictions. Design for Multiple Use Cycles and Design for Recovery further entail considering the effects on the reverse logistics channels. Within literature these circular offerings that last multiple use cycle have been describes as longitudinal value propositions [3]. Design for Multiple Use cycles and Design for Recovery further reflect a move away from developing fixed end-solutions [47].

Circular Business Models and Circular User Engagement can be categorized as strategic competencies as these both aim at interventions at the business strategy level. The strategic competency "Circular Business Models" was identified in previous work before based on a single case study [28]. There was suggested that designers need to get more proficient in business model development. A new and essential element found in this study is the "Circular User Engagement" competency. Literature mentioned the related competencies "considering the user experience, expectation and perception of value during (service) design process" [17] and "connecting reverse logistics with the user" [29] (p. 3). This study shows that the changing relationship with users in a circular economy requires designers working in practice to guide users in the decision-making, use and take-back phase in order to optimally employ certain business models.

The analytical and evaluative nature of the competency Circular Impact Assessment led us to categorize it as normative competency. The need for the Circular Impact Assessment competency shows that designers in practice need support in decision-making and reducing uncertainty during the design process. In previous research the need for the associated competency of "setting circular criteria" [29] (p. 3) was also identified, in relation to guiding circular solutions under development. Yet, in practice useful methods supporting this competency are lacking. We need to understand what circular economy indicators could support decision making in the design process. It also raises the questions whether current environmental assessment methods should be altered to also assess environmental impact over multiple use cycles.

Circular Economy Collaboration can be categorized under what Wiek et al. [19] call the interpersonal competency as this relates to identifying and forming external partnership. Previous research already suggested that collaboration is essential in the context of a circular economy [28,41]. This study shows that in order to develop and implement realistic circular solutions designers need to identify partners and facilitate collaboration. Currently methods to support collaborative activities around designing and implementing circular solutions are limited. An essential and supporting competency within this collaboration is Circular Economy Communication. Designers need to be proficient in creating engaging stories around circular offerings in order to get, for example, circular buy-in and aid in collaborations. Useful tools to aid this communication could be agreed-upon and coherent set of concepts and benchmarks related to design for a circular economy. Previous research

lists limited methods or tools that can aid Circular Economy Communication and subsequently benefit Circular Economy Collaboration.

Interestingly, none of the competencies emerging from our interviews relates to what Wiek et al. [19] formulate as the systems thinking competency. The designers from the study used system mapping in the context of collaboration to analyze current collaborations and assess and identify potential future collaborative needs. Yet, systems thinking according to literature also entails identifying where waste is being created and understanding the relationships between actors [27]. The fact that none of the circular economy competencies identified in this study relate to systems thinking suggest that there is a gap between the literature and practice. Possible explanations could be that while designers might have heard about systems thinking, that there is a lack of knowledge about systems thinking or how to apply it in practice. Other possible explanations are that while designers might have heard about systems thinking they do not see the relevancy of systems thinking or how it can aid the circular design process. Last, applying systems thinking might be too difficult in practice. Yet, future research is needed to be able to formulate a conclusive answer about the lack of systems thinking in practice. Table 5 lists the circular economy competencies for design identified within this study.

Table 5. Sustainability and circular economy competencies for design (extended).

Competencies	Design for Circular Economy	
	Literature	**Practice**
Systems Thinking competency	• Systems thinking [2,24,25] and holistic thinking [26]	• No specific competencies identified
Anticipatory competency	• Considering product wear over time during the design process [17] • "Designing for multiple use cycles" [29] (p. 3) • "Anticipate how the circular offering will evolve over multiple life cycles" [28] (p. 13)	• Foreseeing the consequences of prolonged use and multiple use cycles (Design for Multiple Use Cycles) • Incorporating recovery strategies during the design process while taking into account multiple use cycles (Design for Recovery)
Normative competency	• "Setting circular criteria" [29] (p. 3) • "Assessing circular solutions" [29] (p. 3) • "Estimate the environmental impact on a system level over multiple life cycles" [28] (p. 12) • Consider the consequences on environmental impact of design interventions focused on product lifetime extensions [33]	• Estimating the environmental impact of circular offerings on a system level over multiple use cycles to support decision-making during the design process (Circular Impact Assessment)
Strategic competency	• Considering the user experience, expectation and perception of value during (service) design process [17] • Considering circular logistics and distribution process [17] • "Connecting reverse logistics with users" [29] (p. 3) • Develop the circular business model in conjunction with the product's design [28,33]	• Concurrently developing the circular product, service and business model (Circular Business models) • Engaging users in the use and the (end-of-use) return of products (Circular User Engagement)
Interpersonal competency	• "Circular economy understanding" [29] (p. 3) • "Circular economy storytelling" [29] (p. 3) • "Facilitate collaboration between internal and external stakeholders who play a role in operationalizing a circular business model" [28] (p. 12)	• Identifying, mapping, facilitating and managing the collaboration between external stakeholders in operationalizing a circular business model (Circular Economy Collaboration) • Telling coherent stories about the circular offerings. (Circular Economy Communication)

We observed that the seven circular economy competencies for design are broadly recognized by a large variety of designers in industry, working on different product categories and in different sized companies. This allowed us to formulated a coherent set of competencies. Yet, these competencies are limited by a business perspective. In our results the system thinking competency did not come forward

as clearly present in practice. This might be due to the focus of this study on designers working in industry.

This study reflects that design for a circular economy can be seen as an independent, upcoming field in the ever-evolving sustainability domain, and for which specific competencies, tools, and methods are needed. Further research should investigate how designers could be supported to develop the seven competencies. Future development and testing of methods and tools for these competencies should help designers to contribute to the transition towards a circular economy. In addition, future research could focus on exploring how the seven competencies compare to what is being taught in design curricula and how to teach these competencies in higher education.

While this study provides a current overview of relevant circular economy competencies for design, it might change as the field matures. This reflects what Wiek et al. [19] indicated previously: "Because the field is problem driven, sustainability will continue to be dynamic, and while the field and the problems are evolving our understanding of what kind of competencies are required will evolve as well." (p. 21).

6. Conclusions

This empirical study responds to a growing need in industry and academia for a coherent set of circular economy competencies for design that can guide the development of dedicated courses and training programs. Interviews with 18 design practitioners revealed that there were several discrepancies between the circular economy competencies identified in the literature and those perceived to be most relevant in practice. First, we learned that the emphasis on prolonged and extended use requires designers to master Design for Recovery and Design for Multiple Use cycles (i.e., the anticipatory competency) and Circular Impact Assessment (i.e., normative competency). Second, we did not find the systems thinking competency in practice, although in the literature it is mentioned as a relevant competency for design for a circular economy. Lastly, methods and tools to address the identified competencies are largely lacking or are in a premature stage of development. We conclude that design for a circular economy is an upcoming, independent field in the design for sustainability field that requires specific competencies, methods, and tools. This overview of circular economy competencies for design could help to assess where competency building is needed in design practice. For higher design education, a focus on these competencies in curricula could enable a push for the transition to a circular economy. In short, this paper has given a first overview of competencies that can help shape circular design methodologies and education for decades to come.

Author Contributions: D.S. is the corresponding author of this manuscript. She is the primary author of this manuscript. She was in charge of collecting and analyzing the data, wrote the initial drafts for the full paper, and produced the tables for this manuscript; J.d.K., C.B. and R.B. supervised her in this process, analyzed part of data to ensure intercoder reliability, and contributed to reviewing the paper before it was submitted. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Resource Conservative Manufacturing (ResCoM) project from the European Union's seventh Framework Program for research, technological development, and demonstration under grant agreement no. 603843.

Acknowledgments: The authors would like to thank CIRCO for providing access to their network of designers and the interviewed designers for their participation in this study.

Conflicts of Interest: The authors declare no conflict of interest. The funding sponsors had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the result.

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