Developing a circular strategies framework for manufacturing companies to support circular economy-oriented innovation

Fenna Blomsma[1*], Marina Pieroni[1], Mariia Kravchenko[1], Daniela C.A. Pigosso[1], Jutta Hildenbrand[2], Anna Rùna Kristinsdottir[2], Eivind Kristoffersen[3], Sasha Shahbazi[2], Kjartan Due Nielsen[4], Anna-Karin Jönbrink[2], Jingyue Li[3], Carina Wiik[5], Tim C. McAloone[1]

[1] Technical University of Denmark (DTU), Department of Mechanical Engineering, Nils Koppels All e 404, DK- 2800 Kgs, Lyngby, Denmark
[2] RISE IVF, 43 122 Mölndal, Sweden
[3] Norwegian University of Science and Technology, 7491 Trondheim, Norway
[4] Innovation Center Iceland, Árleynir 2-8, 112 Reykjavík
[5] Technology Industries of Finland, Eteläranta 10, 00131 HELSINKI
[*] Corresponding author: fblo@mek.dtu.dk

Abstract
This paper puts forward the Circular Strategies Scanner: a framework that introduces a taxonomy of circular strategies developed for use by manufacturing companies engaging in circular economy (CE) oriented innovation. Currently, a range of frameworks exists that propose a vision for how to operate in a CE, by identifying and organising relevant circular strategies. However, these frameworks have a limited applicability for specific business types, in particular manufacturing, and are unsuitable for use in CE oriented innovation, due to a lacking ability to support innovation processes through: 1) creating a comprehensive understanding of circular strategies, 2) mapping strategies currently applied and 3) finding opportunities for improved circularity across a range of business processes. This paper addresses these shortcomings by proposing a circular strategies framework for the manufacturing context, titled the Circular Strategies Scanner, which provides a comprehensive set of definitions of circular strategies and directly supports the early stages of CE oriented innovation. With this, the paper contributes to the body of work that develops CE transition methodology.

Keywords Circular strategies framework, closed loop, resource productivity, manufacturing companies, innovation.

1. Introduction

The linear economy is frequently characterised by the presence of structural waste: instances where components, products or materials reach their end-of-use/life prematurely, or where their capacity for value creation is underutilised. To address this, the circular economy (CE) concept proposes a range of efficiency and productivity enhancing activities collectively known as circular strategies, such as reduce, reuse, repair, recycle, restore, cascading, etc (EMF, 2013). In this sense, CE is an umbrella concept: it groups a range of sub-concepts and imbues them with a new meaning by highlighting a shared feature of the sub-concepts (Blomsma and Brennan 2017). This new meaning revolves around the notion that through the application of circular strategies both more value can be created (EMF, 2013) as well as value loss and destruction reduced (Murray et al., 2017).

Although CE has widely been recognised as an idea with potential merit, it has yet to be widely implemented and embedded within business and industry (Haas et al., 2015; Circle Economy 2019). This is in line with the progression of umbrella concepts: when the transformative potential of an idea has been recognised, the attention then turns to operationalising it through frameworks, tools, methods and approaches. This, in turn, allows for further examination of the concept.

For CE this means that there is currently a focus on developing CE transition methodology. This is taking place in a number of aspects relevant for Circular Oriented Innovation (COI) (Brown et al., 2019), such as in business models (Bocken and Antikanen, 2019; Pieroni et al. 2019; Rosa et al,. 2019), metrics and assessment

(Kravchenko et al. 2019; Moraga et al. 2019; Saidani et al. 2019), product design (Moreno et al. 2016; Den Hollander et al. 2017) and the creation of organisational capabilities such as experimentation, value chain innovation and other human factors (Weissbrod and Bocken 2017; Chiappetta Jabbour et al., 2019; Nilsson-Lindén et al., 2019).

Previous academic work focuses on answering 'what' or 'how' to promote COI (Guzzo et al. 2019; Mendoza et al. 2017). However, supporting the early stages of COI through the establishment of a CE vision, i.e. answering why to perform COI, has so far achieved relatively little scholarly attention. Finding the 'why' for a CE transition, requires understanding the type of structural waste in the system, which can be accomplished with a systemic analysis across life cycle stages and various business processes and knowledge areas. This requires various actors within and across business to define and explore problem and solution spaces together (Brown et al., 2019). Specifically, in COI a high-level conceptual understanding of CE needs to be translated into a vision that is useful and meaningful on the level of decision making (Hoffman, 2003; Boons and Howard-Grenville, 2009; Lindkvist and Baumann, 2014). The importance of a shared vision in innovation projects has long since been acknowledged (Pearce and Ensley, 2004; Bititci et al., 2004), and it has been posited to be relevant for both inter and intra organisational COI efforts (Brown et al., 2019).

Currently, there exists a range of frameworks that could potentially be drawn from to support CE visioning. These take the form of circular strategies frameworks, such as the ReSOLVE framework (EMF, 2015), the Performance Economy (Stahel ,2006), Cradle-to-Cradle™ (Braungart and McDonough, 2002), and the Waste Hierarchy (EC, 2008), but also the Ricoh Comet Circle™ (Ricoh, 2018), and the Seven Fronts of Mount Sustainability (Interface, 2018). Importantly, these frameworks can be seen as the visual representations of a vision for how to operate in a CE, since they select, name and organise circular strategies seen as relevant, such that their relationship becomes apparent.

However, Mendoza et al. (2017), Reike et al. (2017) and Blomsma (2018) observed that such circular strategies frameworks can identify or emphasise different (groups of) circular strategies, which can be linked to addressing different types of structural waste. As such, there is a risk that they do not include circular strategies with transformative potential for a particular context. Moreover, Blomsma (2018) points out that little work has been done with regard to ensuring that frameworks are seen as relevant and useful by their intended audiences. For these reasons, there is scope to further develop these frameworks to support visioning in COI. Mendoza et al. (2017), Niero and Hauschild (2017) and Blomsma (2018) therefore call for the development of such frameworks within academia.

This paper answers this call and addresses the question of how to develop circular strategies frameworks such that they are relevant for their intended audiences, in a manner that points to the transformative potential of CE and that assists with unpacking the complexity associated with COI. With this, this paper contributes to the body of work that develops CE transition methodology, focussing on the early stages of COI and engaging the affected audiences in a transdisciplinary approach (Sakao and Brambila, 2018).

As an illustrative case, we develop a circular strategies framework for manufacturing companies1. Manufacturing companies were chosen as the focus as they are important users of materials and energy, produce significant amounts of byproducts traditionally regarded as waste, and form an important employment sector2 and contributor to GDP (Rashid et al., 2013). In addition, manufacturing companies play an important role in the creation of value to their customers and therefore have great potential to decouple this value provision from linear resource consumption.

[1] We use the expression *manufacturing companies* to refer to secondary manufacturing, as opposed to primary production. Moreover, these companies are not contract manufacturers, but have a degree of control over their supply chain.
[2] Sector, as used here, refers to an area of economic activity such as food, medicine, construction, etc. See: https://unstats.un.org/unsd/classifications/.

After clarifying the research gap in the background section and exploring the shortfalls of current circular strategies frameworks to support COI within manufacturing, we continue with setting out the methodology applied in this paper. In the following sections we present the development of the criteria used for designing the new framework and explain the relevant details and outcomes of each subsequent development phase. Furthermore, in section 6, we provide an example of application of the framework in COI. We close with a discussion of the contributions of this paper and directions for further work.

2. Background and research clarification

Describing the complete landscape of circular strategies frameworks is beyond the scope of this paper. However, here we provide an overview of the current landscape of circular strategies framework, through offering a typology of five classes of frameworks. The first four classes describe a continuum where the scope becomes increasingly smaller: (1) the macro level of industrial systems or economies; (2) the meso level of sectors, materials and business types; (3) the micro level of companies; and (4) the nano level covering product (groups) (Saidani et al., 2017). The fifth level adds the layer of (5) networked and regional approaches, through which the other four levels are connected. See Figure 1.

Overview of the landscape of circular strategies frameworks

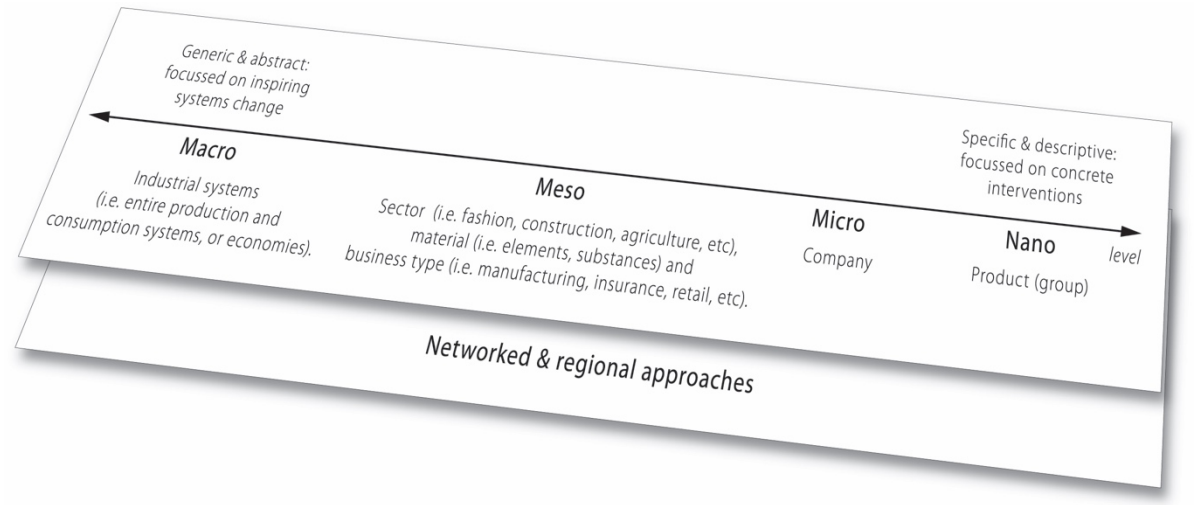


Figure 1. Schematic illustrating the coverage of frameworks on the macro-meso-micro-nano scale, and their relationship with frameworks covering networked and regional approaches.

Considering the landscape of current circular strategies frameworks, a number of observations can be made that explain why current circular strategies frameworks fall short in their capacity to support visioning for manufacturing. First, a circular strategies framework needs to create a comprehensive understanding of circular strategies, as relevant for the purpose (Brown et al., 2019) and context (Blomsma, 2018). Think, for instance, of the difference in the main functions of insurance and finance firms, retail and wholesale businesses, service providers, and manufacturing companies. Different circular strategies will be relevant in these contexts (Rashid et al. 2013; Johannsdottir 2014; Upadhyay et al., 2019).

Currently a multitude of frameworks exist on all levels of the landscape. See for frameworks on the macro level, for example: Allwood et al. (2011), Reike et al. (2017), Bocken et al. (2016), or Braungart and McDonough (2002). Likewise, for meso level frameworks for materials, see for water (WssTP, 2015) and

biomass (ECN, 2018); or fashion and textile frameworks by EMF (2017), Inditex (2016) and Mistra Future Fashion (2018). On the micro level, consider: Gispen's (2018) framework for circular furniture, *The 10 R's of Circularity* by (Mitsubishi Electra, 2018), the Ricoh Comet Circle™ (Ricoh, 2018) (first used in 1994), or the framework used by Konecranes (2018). Likewise, on the nano level: Circular Jeans by Levi Strauss & Co. (2015), and Re-Entry for carpet tiles (Interface, 2016). Lastly, on the networked level, consider: Ehrenfeld and Gertler, 1997; Aguinaga et al., 2018; and Pauli, 2010.

A notable exception of circular strategies frameworks exists on the meso level that apply to specific business types, in particular to manufacturing. One exception is the ResCom framework by Rashid et al. (2013), which targets manufacturing companies. However, this framework is also not well suited to supporting innovation processes, as it includes few circular strategies and contains a limited consideration of business processes.

In addition to creating a comprehensive understanding of circular strategies, a circular strategies framework that supports visioning needs to both map strategies currently applied as well as find opportunities for improved circularity for a range of business processes from a systemic point of view. In this aspect, current frameworks are also lacking as they are often derived or compiled to serve as a summary or overview of a piece of (mostly theoretical) work, as opposed to being purposefully developed for use in COI in and with businesses (Niero and Hauschild, 2017; Kalmykova et al., 2018; Blomsma, 2018; Sakao and Brambila, 2018). However, to establish a vision it is important to both understand the current situation - e.g. what is already being done towards CE, or what capabilities provide a basis for this, as well as to identify what opportunities are present and desirable. Current circular strategies frameworks are not designed to capture an overview of both the current situation and ideas for future innovation.

Another shortcoming of current circular strategy frameworks is that they exhibit ambiguity with regards to the meaning of and relationships between the included circular strategies, allowing the same term to adopt multiple meanings - sometimes with radically different outcomes from a resource perspective (e.g. whether recycling keeps material quality on a consistently high level, or whether it represents downcycling) - or to be rendered inapplicable to some contexts (Reike et al., 2018; Blomsma, 2018).

This paper addresses these shortcomings, by a) providing an example of a process of how a circular strategies framework can be developed for a specific business type with the ability to support COI processes, b) proposing a circular strategies framework for the manufacturing context, resulting in the Circular Strategies Scanner, with c) an accompanying set of definitions of circular strategies (including commonly used synonyms). In addition to this, we provide d) an example of how such a framework can be used to structure and guide the early phases of COI, in order to show the relevance of visioning approaches within CE transition methodology.

3. Methodology

Design Research Methodology (DRM) was applied for the development of the new circular strategies framework for manufacturing, as this method is particularly suited to the deliberate iteration of methods and tools (Blessing and Chakrabarti, 2009). Next, a high-level overview of the aim and activities in each phase is provided. See Figure 2 for an overview: more details are provided in the sections dedicated to each respective phase. The development of the proposed framework took place from November 2017 to July 2019.

Research clarification - This phase, already discussed in the previous section, served to refine the research gap and identify the need for a framework specifically for manufacturing companies.

Descriptive study I - This phase served three goals. First, a list of circular strategies to be included in the framework was compiled. Second, criteria that could be used to guide the development process of the new

framework were articulated, which, third, were used to choose an existing framework as the basis for the development of the new framework. A series of workshops and meetings were held for this purpose. Iterations of the strategies list, their definitions and the framework requirements were performed throughout the project, but are presented as a single phase for clarity and brevity.

Prescriptive study I - A series of workshops and follow-up meetings were held to conceptualize and develop a first version of the circular strategies framework, as well as the corresponding clarifications and elaborations on strategies, and the relationship between them.

Descriptive Study II - In this phase the applicability and usefulness of the framework in the context of the manufacturing sector was evaluated and improvement opportunities sought. Workshops were performed with three manufacturing companies from the heavy machinery, electronics and furniture sector.

Prescriptive study II - A series of meetings was held to discuss the implementation of the improvement opportunities, based on insights from *Descriptive Study II* and the iterations of the *Research Clarification* and *Descriptive Study I* phases. A second version of the framework and a final list of strategies and their definitions were developed during this phase.

Moreover, the approach applied was deliberately transdisciplinary. That is, it aimed for establishing "a common system of axioms for a set of disciplines," which was achieved in two ways (Sakao and Brambila-Macias, 2018:1400), see also Figure 2:

(1) *Adopting a systemic view* - In the context of (more) circular manufacturing this means the alignment of the different business processes, which together contribute to the creation of circular systems. The perspectives of these processes therefore need to be included.
(2) *Inclusion of non-academic stakeholders* - Creating (more) circular manufacturing systems entails affecting changes in manufacturing companies. As such, it is important to acknowledge the perspective of manufacturing companies in the development of the new framework.

The first type of transdisciplinarity was implemented through the creation of the CIRCit research consortium[3] to represent the knowledge related to business model strategy, product design, and a range of operational processes such as sourcing, manufacturing, logistics, through-life support, digital technologies and end-of-life operations, but also sustainability aspects and value chain management.

The second type of transdisciplinarity was implemented through application of the framework on retrospective company cases, as well as applying the framework in ongoing research that is actively supporting companies in implementing circular practices. Furthermore, the consortium contained representatives of the interests of manufacturing companies, such as industry associations. Through this, the perspective of 'real-world' considerations was added. Next, the outcomes of each phase is presented.

[3] See for more information about the consortium: www.circitnord.com.

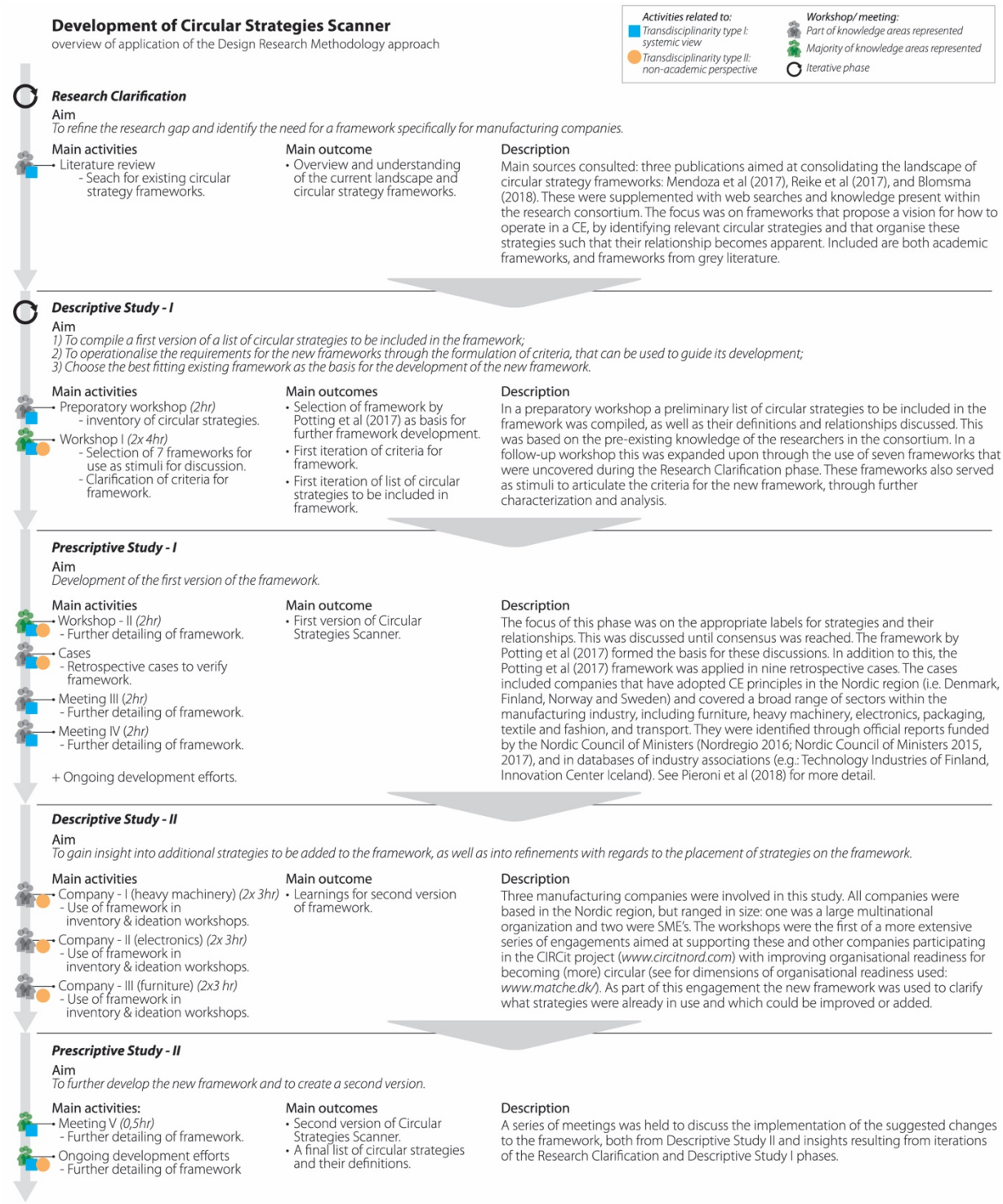


Figure 2. Schematic illustration of the approach followed for the development of the Circular Strategies Scanner.

4. Descriptive Study I - criteria for a circular strategies framework for manufacturing companies

This phase served to establish a foundation for the development of the new framework. This was done in the following manner, see also Figure 2.

4.1. Rationale behind Descriptive Study I

Due to the lack of suitable meso level frameworks with a business type orientation, macro frameworks were used as a starting point with the aim to adapt their generic applicability and generative capacity for manufacturing companies. From the macro frameworks 1) relevant circular strategies were extracted, and 2) criteria that could be used to guide the development process of the new framework were articulated, which 3) were used to choose the best fitting existing framework as the basis for the development of the new framework. In particular, seven macro level frameworks uncovered during the Research Clarification phase were used: Thierry et al. (1995), Parkinson and Thompson (2003), Allwood et al. (2011), Bocken et al. (2016), Nussholz (2017), Potting et al. (2017), and Blomsma (2018). These were included based on 1) their range of relevant strategies for the manufacturing context, 2) their inclusion of definitions and/or examples of these strategies and 3) representing a broad range of approaches to classify or organise the strategies in relation to each other. This served to have contrasting definitions and approaches that could be discussed and analysed.

4.2. Outcomes Descriptive Study I

The final version of the list of included strategies, their definitions and examples, which continued to be iterated throughout the development of the framework, can be found in Table 2 (see section 7. *Prescriptive study II*). Here, the focus is on the five criteria for the new framework that were developed to detail the main functions of a circular strategies framework (create understanding of CE, map current CE initiatives, generate ideas for increased circularity). The criteria were iterated until they represented five clear requirements for the development of the new framework. This section concludes with the selection of the best fitting existing framework.

Criterion #01: A tool for inspiring, motivating and aligning people

In innovation processes it is important to invoke relevant frames, acknowledge cognitive principles (which involve cognitive limits, but also principles of attention, inspiration and motivation) and, in collaborative settings, to consider the alignment of understanding, mindsets and interests between different stakeholders. Language, both visual and written, plays an important role in this: it helps directing attention, summarising and synthesising information from internal and external knowledge sources and it supports orientation towards relevant aspects of the context (Biloslavo et al., 2018; Breuer et al., 2018) and in the creation of a shared vision, also in the context of CE (Blomsma, 2018). Therefore, in line with the frameworks discussed above, the proposed framework should 01) represent a complex phenomenon in an easily accessible manner in order to inspire, motivate and align people.

Criterion #02: A tool for describing current situations and identifying opportunities, both incremental & transformative

A framework suitable for use by a wide variety of manufacturing businesses, cannot be broad in the sense of the frameworks on the macro level, as it will lose relevance. At the same time, it can also not be specific in the sense of the company and product frameworks, as this would mean it is limited in its reach and impact. However, the new framework should be suitable for describing both current initiatives and have the capacity to systematically explore relevant strategies and identify new opportunities. As such, the new framework should balance the strengths of the macro and meso level frameworks - which are generative and allow for the exploration of alternatives, with that of the micro and nano level frameworks - which offer greater specificity in relation to the context in which strategies are applied. Thus, the new framework should: 02a) balance the generation of new ideas, with that of describing existing situations. This indicates that it is preferable to include a diverse set of circular strategies, as opposed to high-level aggregated groups of strategies.

Furthermore, opportunity finding needs to point to the potential for improving existing strategies, as well as to radically different ways of achieving goals and creating, delivering and capturing value. This can involve the design, production and/ or transport of physical products, but it can also require a change in the business logic and operations that changes how products are commercialized and consumed. Think of the implementation of access-over-ownership models, or radical dematerialisation through a change in paradigm. As such, the framework should 02b) provide an overview of the spectrum of available strategies ranging from incremental to transformative. This indicates that the set of included strategies should cover strategic as well as operational business processes.

Criterion #03: A tool for facilitating alignment of changes in business processes and capabilities
Circular strategies frameworks aimed at specific business types need to provide insight into which business processes relevant for that business type need to be aligned. This means, following Allwood et al. (2011), Potting et al. (2017) and Reike et al. (2018), that the new framework should indicate which circular strategies may apply to which flows. In the manufacturing context, this implies 03) indicating which strategies affect which business processes and related capabilities.

Criterion #04: A tool for bringing together efficiency and effectiveness strategies, and strategy configurations
Following e.g. Pauli (2010), Stahel (2006), Potting et al. (2017), Reike et al. (2018) and EMF (2015), we adopt the view that both resource-efficiency and resource-effectiveness are important in the manufacturing context. The new framework therefore should: 04a) explicitly include the reduction and avoidance of resource use and impacts, as well as resource productivity strategies aimed at continued use and value delivery.

Moreover, many manufacturing companies operate in complex scenarios, that can be thought of as circular configurations: situations where two or more circular strategies are present (Blomsma and Brennan 2017, Blomsma 2018). Think of product/ service systems where direct reuse, but also repair, refurbishment and remanufacturing are taking place, in addition to the recycling of materials. As such, the proposed framework should: 04b) allow for generating insight into circular configurations.

Criterion #05: A tool for alignment with drivers: value creation & capture orientation
Businesses need to create and capture value to continue their activities. It is widely acknowledged that circular strategies have the capacity to contribute to this. However, not many current frameworks support the identification of the type of value that can be captured through which strategies. The new framework therefore needs to be aligned with the perspective of systemic value creation and capture. Support in identifying this can enable assessing and measuring outcomes and tracking potential deviations from the planned future state, which is fundamental to transition management (Breuer et al., 2018). As such, the proposed framework: 05) has to point to the value drivers that circular strategies can contribute to. That is: the framework has to help users identify relevant contributions to value creation and capture, such as improved efficiencies, supporting optimal use during the use phase, and value recovery opportunities, resulting in either financial or non-financial gains within or outside the company (Circle Economy et al., 2016). As these may be relevant for business shareholders, but also suppliers and customers, the environment and society they need to be formulated such that relevance for these stakeholders can be easily appreciated.

Next, the seven frameworks were compared and rated on these criteria, see Table 1. Although none have a perfect score, the framework by Potting et al. (2017) scores the highest: it represents a complex phenomenon in an easily accessible manner (criterion 01), contains a comprehensive set of circular strategies (criterion 02b), includes efficiency as well as effectiveness strategies (criterion 04a) and points to value drivers that circular strategies can contribute to (criterion 05). This framework was therefore chosen as a basis for further development of the new framework, with its relevance for different business processes and capabilities (criterion 03) identified as in need of further improvement.

Criteria The new framework should:	Bocken et al (2016)	Allwood et al (2011)	Parkinson & Thompson (2003)	Thierry et al (1995)	Potting et al (2017)	Nussholz (2017)	Blomsma (2018)
01) A tool for inspiring, motivating and aligning people.	+	++	0	++	++	+	+
02a) Balance the generation of new ideas, with that of describing existing situation.	0	+	0	+	++	+	0
02b) Provide an overview of the spectrum of available strategies ranging from incremental to transformative.	+	+	0	+	++	++	0
03) Indicate which strategies affect which business processes.	0	+	0	+	+	0	0
04a) Explicitly include the reduction and avoidance of resource use and impacts, as well as resource productivity strategies aimed at continued use and value delivery.	+	+	0	0	++	++	0
04b) Allow for generating insight into circular configurations.	+	++	0	++	++	+	+
05) Has to point to the value drivers that circular strategies can contribute to.	++	0	0	+	++	+	++
+++ = framework satisfies criterion very strongly, ++ = framework satisfies criterion strongly, + = framework satisfies criterion moderately, 0 = framework doesn't meet criterion or only marginally.							

Table 1 - Comparison of the seven frameworks that were used in Descriptive Study I using the development criteria.

5. Prescriptive Study I

During this phase the first version of the new framework was developed, through adding detail to Potting et al. (2017) as relevant for the manufacturing business type, guided by the criteria established in the above and the exploratory case studies (see Pieroni et al., 2018). The focus was on the appropriate labels for strategies, and how to convey the relationship between the included strategies.

5.1. Outcomes Prescriptive Study I

The outcomes of this phase is discussed in terms of the adaptations of the Potting et al. (2017) framework that were made. Only the major adaptations are elaborated upon: see for the first version of the framework Figure 3 and the complete set of changes Appendix A. See for definitions and examples of individual strategies Table 2 (section *7. Prescriptive study II*).

Major adaptations #01 and #02: Organisation of circular strategies according to business processes, and greater specificity for 'Reduce'

The preliminary list of circular strategies from the previous phase was organised according to the business processes as typically found in the manufacturing context, to meet criterion #03. For this, the process of transformation of raw materials into finished or intermediate goods was divided as follows. First, two areas that are related to the corporate strategy were identified: the first is changing the paradigm of practices and was named 'Replace,' and the second is a reconsideration of how value is delivered, entitled 'Rethink.' The former strategy enables radical dematerialisation through different ways of performing functions (e.g. functional replacement or new practices), which can be enabled by new technologies. This strategy was renamed from Potting and colleagues' 'Refuse' (see Medium adaptation 1 in Appendix A). The latter strategy involves new business models that are more resource efficient, such as access-over-ownership offerings, enabled by commercial models based on leasing, renting or pay-as-you-go. As such, 'Replace' concerns the

delivery of functionality through radically different means, whilst 'Rethink' delivers similar functionality through different customer relationships and which may involve a redefinition of the functional unit.

The remainder of the framework concerns operational processes. Potting et al's (2017) 'Reduce' was further divided to make its application to the following operational processes explicit: 'Raw materials and sourcing,' 'Manufacturing and logistics' and 'Product use/ operation.' This indicates that in these phases, the focus is on efficient use of resources and the reduction of harmful impacts.

The next two operational process areas respectively contain various end-of-use and end-of-life strategies. The first contains the strategies 'Upgrade' (see Minor adaptation 2), 'Repair & Maintenance' (see Minor adaptation 4), 'Reuse,' 'Refurbish,' 'Remanufacture,' and 'Repurpose'; and the second which contains the strategies 'Recycle' and 'Recover' (see Minor adaptation 1).

Major adaptation #03: Addition of the relationship between business processes

To capture the different relationships between the strategies (criterion 04b), a visual structure consisting of three levels has been created: the first occupied by 'Replace,' the second by 'Rethink' and the third by the remaining strategies. This is indicated by the relative placement of the boxes containing the strategies and the addition of arrows. This signals that, within the manufacturing context, some relationships between circular strategies are of a hierarchical nature, and some exist in the form of trade-offs and synergies. An example of a hierarchical relationship: 'Replace' may preclude the use of certain other circular strategies, when, for instance, a physical product is replaced by a virtual service. On the other hand, the application of 'Rethink' can require the support of repair and maintenance strategies to be viable, such as in certain product/service system offerings. As such, the application of either 'Replace' or 'Rethink' requires that the relevance of all strategies on the levels 'below' should be evaluated, as their relevance may change when these strategies are applied.

Circular Strategies Scanner - v1.0

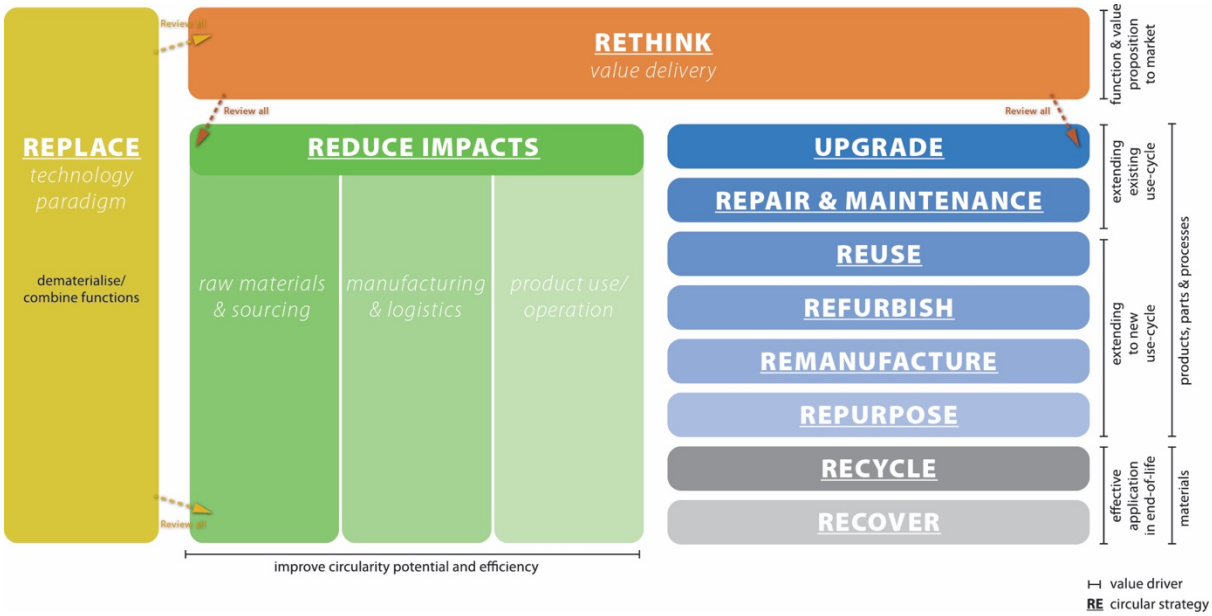


Figure 3 - The first version of the Circular Strategies Scanner.

Examples of other relationships include trade-offs: the choice, for instance, for certain durable materials such as composites may impede recycling. In this case, a strategy that facilitates product longevity, conflicts with recycling the material at the end-of-life. On the other hand, certain interventions may cause cumulative or

reinforcing effects, such as choosing a renewable material that at the end-of-life can be safely composted, allowing this single intervention to cover two circular strategies synergistically; the sourcing of materials that can be renewed and the 'recovery' of nutrients at the end-of-life. For this reason, the strategies that reduce impacts and that affect end-of-use/ life are placed on the same level. When considering these strategies, therefore, it should be examined if trade-offs and/ or synergies with other strategies on this level exist.

With this structure the new framework departs from the hierarchy that Potting and colleagues use. However, the value drivers have been preserved and further refined, in line with the different business processes (see Medium adaptations 2 and 3).

6. Descriptive Study II

In this phase the framework was tested in workshops within three manufacturing businesses from the heavy machinery, electronics and furniture sectors. The aim was to gain insight into additional strategies to be added, as well as into refinements with regards to the placement of strategies. Moreover, this section provides an example with regards to how a circular strategies framework can be used in the early stage of COI.

6.1. Use of the new framework in workshops in Descriptive Study II

With each business a two-part workshop was carried out. The first part mapped the circular strategies currently applied within a product or service (category). Participants were asked to prepare by classifying their offering (products, services or PSS), and to identify and describe the strategies currently applied. In the workshop, all strategies were mapped onto the Scanner and discussed: the current implementation level of the strategies, as well as their respective affinities to the business and their resource efficiency impact (e.g.: percentage of total sales or revenues, percentage of sold products recovered for end-of-use/life treatment). The second part of the workshop focused on scanning for new opportunities to enhance or append additional strategies, through the evaluation of the current state and the identification of gaps and improvement hot spots. Case examples of other companies employing strategies across the full range of strategies covered by the Scanner were used to stimulate the discussion with participants.

In total, each workshop lasted approximately six hours and involved participants with diverse skills and expertise, such as marketing and sales, services and product development, after sales and customer services, operations, corporate social responsibility, IT, business strategy and finance. Moreover, representatives from the business leadership or top management participated in all workshops. The number of participants varied from three to ten, according to the business size.

6.2. Outcomes Descriptive Study II

An example of the mappings created in both phases of the workshop can be found in Figure 4. The top part represents individual initiatives currently applied by one of the companies (one initiative per number). This represents current CE initiatives or current capabilities that can contribute towards increased circularity. The bottom represents improvement areas: circular strategies that could be improved or scaled up, or strategies that could feasibly be added. Comparing the current state with new opportunities, it can be seen that ideas were generated that increased the coverage of circular strategies, some even developing into more advanced concepts when synergies between circular strategies were identified.

During the workshops with the companies, the framework functioned as a boundary object (Star and Griesemer, 1989) for different participants to align their perceptions. That is: clarifying the current state together allowed participants to build a common picture of their organisations' ongoing CE initiatives and current capabilities, and to align their understanding of their nature and maturity. Moreover, the shared

exploration of new opportunities helped the participants to share their perceptions of these opportunities, and set priorities for their innovation pipeline. In all cases the visioning exercise helped to identify why and where to focus, whether in relation to the development of circular business models, applying circular product design principles, the application of smart technologies, the assessment of potential initiatives in relation to their sustainability impact and/ or areas where collaboration with other stakeholders needed to be sought[4]. As such, this visioning exercise facilitated with the Scanner served to guide and direct the COI process to relevant initiatives and appropriately set the scope for these efforts early on. Direct feedback provided by individual participants supports this. Representative responses were “quite helpful”, “great tools” and “visualization with the boards helped the conversation a lot.”

However, observations were made that were used to improve the framework further. First, it was noted that efficient logistics is relevant throughout a product’s life, and not just before, during and after manufacturing. That is: for operations extending existing life cycles or those that extend the product life to new use-cycles and in recovering materials for end-of-life treatment, logistics must be cost- and carbon efficient. It should be placed in such a way to indicate this broader relevance.

Moreover, it was observed that it is also possible to use the sourcing stage as an opportunity to recapture waste that has already entered the environment. The various projects around recovering plastic from the oceans are examples of this (The Ocean Cleanup 2018, Plastic Oceans 2018), and the framework should also highlight the possibility of sourcing such materials. These observations led to the Medium adaptations 1 and 2 discussed in the next section, see also Appendix C.

[4] For more on this, see the CIRCit website (circitnord.com).

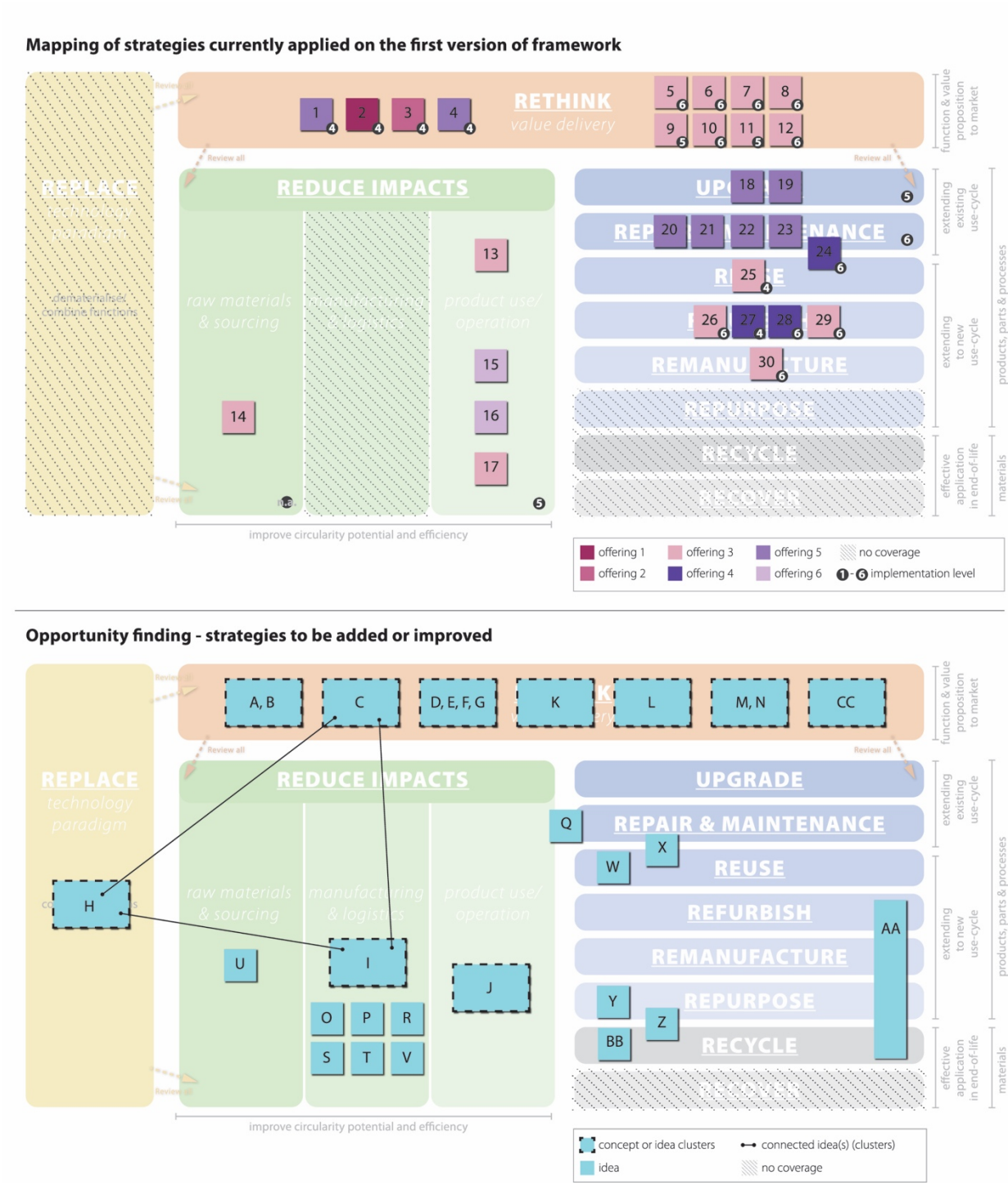


Figure 4 - Example of how the first version of the Circular Strategies Scanner was used in a two-part workshop with one of the companies participating in the CIRCit project. One or double letters are used per strategy: connected or grouped ideas represent closely related ideas that together constitute a new concept. Results are anonymised for reasons of confidentiality.

7. Prescriptive study II

The aim of this phase was to develop a second version of the framework on the basis of the identified improvement opportunities. The main activities were ongoing development efforts, supplemented by a series of meetings held to discuss the implementation of the suggested changes stemming from *Descriptive Study II* and the continued iteration of the *Research Clarification* and *Descriptive Study I.*

7.1. Outcomes Prescriptive Study II

No major adaptations were made, therefore the focus here is on medium adaptations: see for the second version of the framework Figure 5 and the complete set of changes Appendix B. See for definitions of individual strategies Table 2.

'Logistics' was assigned a separate layer such that it encompasses all the operational process areas. In addition to this and in a response to additional sources considered, 'Energy' was added as a layer encompassing all circular strategies (Cullen, 2017; Mestre and Cooper, 2017). That is: circular strategies should be considered with the intent to reduce overall energy consumption, and the use of clean(er) and renewable sources wherever possible.

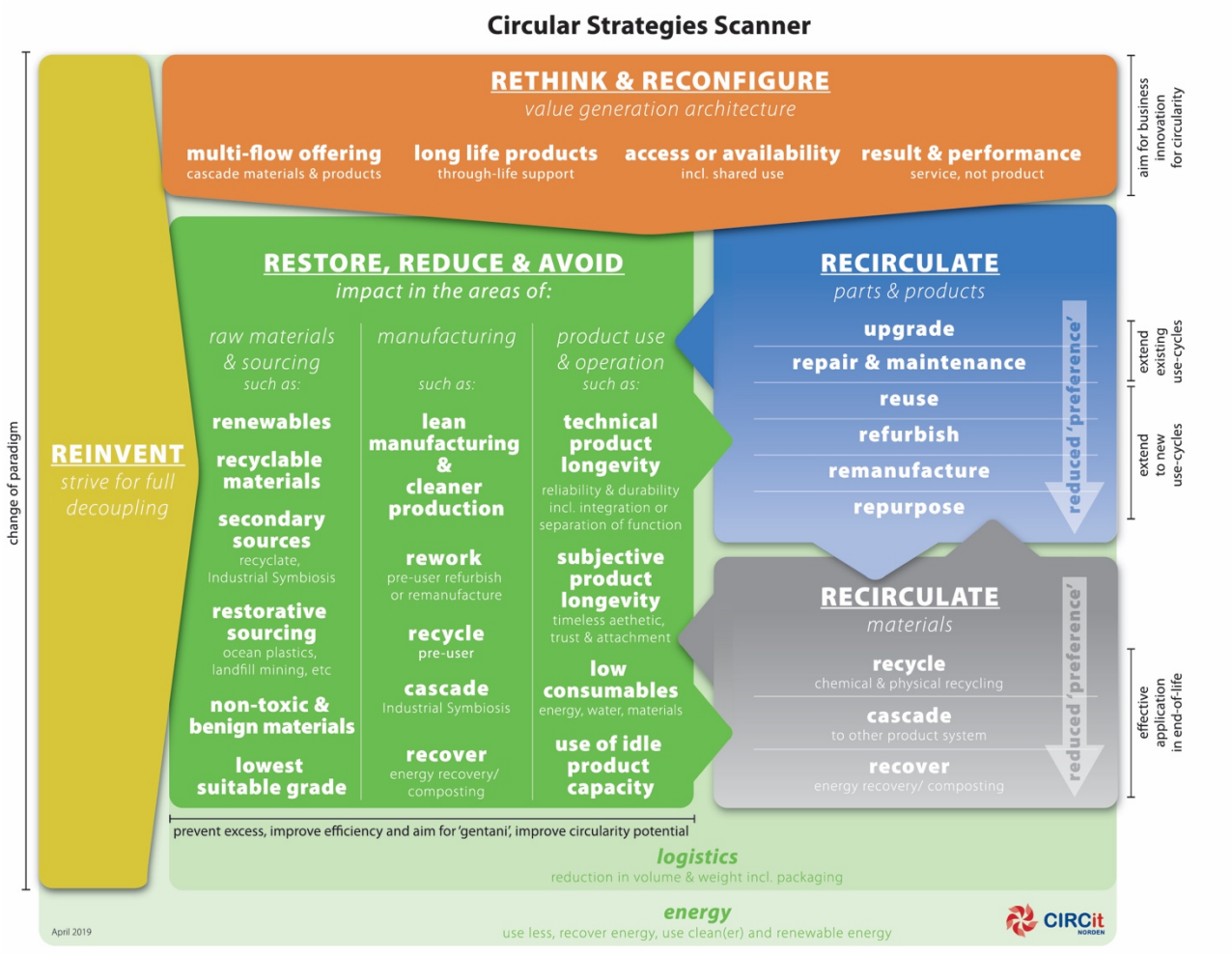


Figure 5 - The second version of the Circular Strategies Scanner.

Moreover, the heading 'Reduce impacts' was changed to 'Restore, reduce & avoid' to more fully reflect the range of strategies relevant for raw materials and sourcing, manufacturing, and product use and operation. Also, more detail was added to the visual representation of the framework, which entailed the addition of

suggested strategies in this area (see Minor adaptation 2). These strategies are meant to be inspirational, rather than exhaustive. In some cases this resulted in allocating strategies to multiple places in the framework, which is in line with Potting et al. (2017) and Reike et al. (2018). Recycling, for instance, can be found in both the category Restore, Reduce and Avoid, as well as in the category Recirculate - Materials. This reflects the fact that pre- and post consumer recycling can take place. Similarly, cascading, or industrial symbiosis can take a variety of different forms: as a sourcing strategy, as a way of valorise manufacturing waste, but also as an end-of-life strategy for materials. These multiple occurrences are also due to departing from the hierarchical structure used by Potting et al. (2017) (see also section *5. Prescriptive Study I*). For clarity descriptors have been added to signal the specific application of a strategy (see Minor adaptation 3).

Similarly, detail was added to the Rethink & Reconfigure category to clarify the framework's relationship with business models aspects. Two sources were consulted for this: Bocken et al. (2016) and Tukker (2004), chosen because of their seminal importance in the CE field (Pieroni et al. 2019) These respective typologies were synthesised into four main categories that cover circular business model strategies available to manufacturers and that represent a fundamental change to the logic of how such a business operates: 'Multi-flow offering,' 'Long-life products,' 'Access or availability,' and 'Result and performance.' This, as opposed to including strategies that are more appropriately thought of as supporting operational strategies such as efficiency and encouraging sufficiency.

Strategies included in the Circular Strategies Scanner (further developed from Potting et al. 2017)		
Driver	**Strategy** Synonyms	**Area of application or sub category** **Recirculation strategy** & synonyms ***Definition*** *(specifics)* • **Example practice(s)/ specifics**
Enable smarter business concepts through striving for full decoupling.	**Reinvent** Refuse	**The paradigm** *Make physical products redundant by offering the same function or combined functions, usually enabled by radically different product, technology or both (Potting et al. 2017).* • The 'bring-your-own' movement facilitates replacing such single use items such as coffee cups. • Music and video streaming services negate the need for data carriers such as CDs and DVDs. • Multi-functional devices such as smart phones combine the functionality of multiple devices (camera, GPS, phone, calculator, alarm clock, sound system, computer) in a single device.
Enable smarter business concepts through business model innovation for circularity. Products tend to not radically change, although the technology can evolve.	**Rethink & reconfigure** Revolution Replace	**Business models** Multi-flow offering – cascade materials, parts & products *Extend the life of materials or products in a manner that exploits their residual value and becomes a significant part of the offering of the business. May involve providing new forms of value (Bocken et al., 2016).* • Leesmap (magazine subscription where the price decreases with the age of the magazines). • British Sugar (from the core-business of sugar, to also selling many different co-products). Long life products – through- life support *Extend the life of products through offering support during their lifetime (Tukker, 2004).* • Provision of maintenance, offering of repair services, or sales of spare parts. Access or availability – incl. shared use *Satisfying user needs without transferring ownership of physical products. Instead, user or consumer pays for access to the product for a certain period of time (Tukker, 2004).* • Bike or car sharing services (e.g. Bycyklen in Copenhagen, Santander Cycles in London, and many other cities around the world; Drive Now, Green Mobility, Zipcar, Blablacar). • Clothing rental and subscriptions (e.g. Rent the Runway, Vigga, Mud Jeans). Result & performance – service, not product *The provider of the service delivers an outcome for the customer (Tukker, 2004).* • Performance contracts (Rolls Royce - Power by the Hour).
Prevent excess, improve efficiency and aim for 'gentani', improve circularity potential.	**Restore, reduce & avoid**	**Raw materials & sourcing** *Improve circularity potential and efficiency in the sourcing process (Mestre and Cooper, 2017).* • Sourcing of renewables. • Sourcing of recyclable materials. • Secondary sources (recycled materials, Industrial Symbiosis, other cascades). • Restorative sourcing (Use former 'wastes' as input: Landfill re-mining or using ocean plastics). • Use of non-toxic or benign materials (to facilitate re-absorption in natural cycles). • Use the lowest suitable grade of materials suitable (Reserve the highest-quality resources for the most demanding task, and use used resources further down the chain). **Manufacturing** *Improve circularity potential and process efficiency in product manufacture through consuming fewer natural resources or energy, aim for 'gentani' (the absolute minimum input required to run a process) (Potting et al., 2017).* • Lean manufacturing & cleaner production (use less energy and materials, treat wastes, etc). • Rework (pre-user refurbishment or remanufacture). • Recycle (pre-user recycling). • Cascade (find uses for manufacturing waste: internally/ at other facilities (Industrial Symbiosis)). • Recover (energy recovery, or recovery of biological nutrients). **Product use & operation** *Improve circularity potential and efficiency in product use and operation through wiser use and operation of products (usually enabled by digital technologies), and aim for 'gentani' (the absolute minimum input required to run a process) (Potting et al., 2017; Reike et al., 2018).* • Enable product longevity through high product integrity and robustness. • Use idle product capacity (historical usage data can be used for improvements such as better scheduling (of downtime), and (give insight into the possibilities for) pooled or shared use). • Low consumables of energy, water and materials during product use and operation. ***Logistics*** *Improve process efficiency in logistics operations, aim for 'gentani' (minimum input into a process (Greenbiz, 2014)* • Combine forward & return logistics. • Incentivize eco-friendly driving and transport. • Minimize, reuse or recycle (transit) packaging. ***Energy*** *Improve energy efficiency and use clean(er) sources of energy (Cullen, 2017; Mestre and Cooper, 2017).* • Use less energy • Renewable energy

Strategies included in the Circular Strategies Scanner *(cont).*		
Driver	**Strategy**	**Area of application or sub category** **Recirculation strategy** & synonyms ***Definition*** *(specifics)* • **Example practice(s)/ specifics**
Extend existing use cycles with the purpose of capturing (residual) value or to reduce value loss from continued use of parts and products	**Recirculate**	**Parts & products**
		Upgrade – Update, modernize, renew, retrofit, rebuild, overhaul, revive.
		Extend existing use cycle by adding value or enhancing the function of a product in respect to previous versions (Parkinson and Thompson, 2003; Potting et al., 2017).
		• Aesthetic upgrades (i.e. changing the coat or sleeve of a product due to a new preference). • Functional upgrades (i.e. software upgrades, hardware upgrades).
		Repair & maintenance – Corrective, condition based, predictive and prescriptive maintenance
		Extend existing use cycle by countering wear and tear, and correcting faulty components of a defective product/part to return it to its original functionality. *((Partial) disassembly envisioned, limited warranty may be issued).* *(Thierry et al, 1995; Stahel, 2006).*
		• Providing a product with a service, which may involve the lubrication of critical parts, checking fasteners, the tension of chains and cables, the replacement of worn-out parts, etc. • Repair may involve the restoration or replacement of faulty parts and components.
Extend to new use cycles with the purpose of capturing (residual) value or to reduce value loss from continued use of parts and products.		Reuse – As-is reuse, redistribution, product cascading, minimise.
		Extend to new use cycle by reusing a part/ product (discarded/ not in use) that is still in good condition and can fulfil its original function in a different use context (new customer/user). *(May involve a minimum amount of condition monitoring such as cleaning or repackaging. No warranties are provided and no disassembly is involved.)* *(Saavedra et al., 2013)*
		• Selling used goods on platforms such as E-bay, • Return and resale of second hand goods through stores, such as Patagonia and Bergans. • The xStorage Home system (by Nissan and Eaton) gives old lithium-ion batteries from Nissan Leaf a second life inside of homes and businesses as backup and solar storage batteries.
		Refurbish – Recondition, retrofit, refresh, remodel.
		Extend to new use cycles by returning a part/ product (discarded/ not in use) to a satisfactory working condition that may be inferior to the original specification. *(This may involve: cleaning, repairing, resurfacing, repainting, re-sleeving. Partial disassembly envisioned*. In the case of traditional product sales, a warranty for all major parts may be issued (less than the newly manufactured equivalent)).* *(Ijomah, 2002, 2009; Saavedra et al., 2013).*
		• For example: taking in relatively modern, but disused white goods and performing repairs and/ or replacing lost parts and finding new users for the refurbished products (e.g. Norsk Omburk).
		Remanufacture – Rebuild, overhaul, remake.
		Extend to new use cycles by returning a product (discarded/ not in use) to at least Original Equipment Manufacturer (OEM) performance specification and quality. *(Usually more rigorous and costly than refurbishment and involves total disassembly and reassembly. In the case of traditional product sales, a warranty that is at least equal to that of a newly manufactured equivalent may be issued).* *(Ijomah, 2002, 2009; Saavedra et al., 2013).*
		• Renault engine blocks
		Repurpose – Alternate use.
		Extend to new use cycles by using a product (discarded/not in use) or its parts for different functions (Potting et al., 2017; Reike et al., 2018).
		• Mærsk providing containers to fit housing purposes in Copenhagen Village. • Using product packaging as storage or glassware (Nutella, Douwe Egberts).
Effective application in end-of-life of materials with the purpose of capturing (residual) value or to reduce value loss from continued use of materials.	**Recirculate**	**Materials**
		Recycle
		Extend material lifespan by processing them in order to obtain the same or comparable quality (Allwood et al., 2011).
		• Can-to-can recycling in beverage cans. • Chemical recycling of nylon.
		Cascade – Downcycling, upcycling.
		A subsequent use that significantly transforms the chemical or physical nature of the material (Sirkin and Ten Houten, 1994).
		• Repurposing of used clothing as an insulation material. • Used coffee grounds from coffee shops processed into biofuel, as medium for cultivation of edible mushrooms, for use in beauty products, etc.
		Recover
		Recover energy or nutrients from composting or processing materials. (Reike et al., 2018).
		• Incineration, pyrolysis or anaerobic digestion (recovery of energy). • Composting (recovery of biological nutrients).

Table 2 - Overview of the definitions of the circular strategies as used in the Circular Strategies Scanner.

8. Discussion

The Circular Strategies Scanner illustrates how to support visioning in COI processes, through supporting the explication of CE, mapping current CE initiatives, and generating ideas for increased circularity. With this, the framework of Potting et al. (2017) was significantly improved upon for the manufacturing context, see Table 3.

Criteria **The new framework should:**	**Potting et al. (2017)**	**Circular Strategies Scanner - v2.0**	**Summary of improvements that were realised**
01) A tool for inspiring, motivating and aligning people.	++	+++	*Improved capacity to serve as a boundary object where stakeholders can clearly identify their (influence on) activities, and see the applicability and relevance of circular strategies (see also the criteria below).*
02a) Balance the generation of new ideas, with that of describing existing situation.	++	+++	*The Scanner can directly and without transformations be used as a tool for mapping the circular strategies that are present in a situation, as well as for exploring what strategies can be improved or added (see section 6).*
02b) Provide an overview of the spectrum of available strategies ranging from incremental to transformative.	++	+++	*The Scanner groups circular strategies according to their potential for change in circularity levels. Strategies that can be thought of as having potential for incremental change are grouped under* Restore, reduce & avoid*; strategies that aim for higher levels of circularity through business model innovation are grouped in* Rethink & reconfigure*; and strategies that radically transform both business and user practices and achieve radical decoupling are placed in* Reinvent*.*
03) Indicate which strategies affect which business processes and related capabilities.	+	++	*The circular strategies in the Scanner are organised according to the business processes they apply to.* Reinvent *and* Rethink & reconfigure *represent groups that affect business strategy, and the remaining groups respectively affect operational processes, ranging from raw materials and sourcing, manufacturing, product use and operation, to the recirculation of parts and products, and materials.*
04a) Explicitly include the reduction and avoidance of resource use and impacts, as well as resource productivity strategies aimed at continued use and value delivery.	++	+++	*The Scanner covers a wider range of circular strategies, giving a more comprehensive overview of circular strategies that aim for the reduction and avoidance of resource use and impacts, as well as those that improve resource productivity strategies.*
04b) Allow for generating insight into circular configurations.	++	+++	*The Scanner implements a means of systematically exploring connections between circular strategies, through organising them in three 'levels' that indicate their relationship. This relationship can be bi-directional: e.g. a change in circular strategies in* Restore, reduce & avoid *may impact the circular strategies in* Recirculate and vice-versa*; or it may may be a unidirectional relationship where a change in* Reinvent *requires the reexamination of the relevance of circular strategies in* Rethink & reconfigure*, or where a change in* Rethink & reconfigure *requires a reconsideration of the strategies applied in* Restore, reduce & avoid.
05) Has to point to the value drivers that circular strategies can contribute to.	++	+++	*Each group of circular strategies in the Scanner is clearly linked to a value driver that aids its users in identifying relevant contributions to value creation and capture, such as improved efficiencies, supporting optimal use during the use phase, and value recovery opportunities, pointing to opportunities for either financial or non-financial gains within or outside the company.*
+++ = framework satisfies criterion very strongly, ++ = framework satisfies criterion strongly, + = framework satisfies criterion moderately, 0 = framework doesn't meet criterion or only marginally.			

Table 3 - Overview of the the improvements that the new framework makes in relation to the framework by Potting et al. (2017) that was used as a basis for its development.

A strength of using the Scanner in COI is that it provides a way of systematically exploring circular strategies. It thus provides guidance in identifying what business areas eco-innovation for CE is possible or necessary. For instance, when improved recycling is identified as an opportunity, the Scanner indicates that other circular strategies in the operational areas of raw materials and sourcing, manufacturing, product use and operation, and the recirculation of parts and products may be affected. Such impacts may be synergistic and result in increased overall circularity (e.g. the choice to change to a recyclable material to enable end-of-life recycling also enables recycling of waste within the manufacturing process), or they may take the form of trade-offs and require additional management or development for resolving them (e.g. changing to a recyclable material negatively affects the technical longevity of a product). Further work could focus on providing additional guidance with regards to how to systematically identify synergies and trade-offs.

Application of the Scanner furthermore strengthens the connection between eco-innovation and CE, by linking it with transformative innovation (De Jesus et al. 2018). It does this in two ways in COI processes. First, due to possibilities uncovered in the operational area, it can trigger a re-evaluation of the value generation architecture. Second, when the value generation architecture is the starting point, the Scanner indicates that the role of the circular strategies on the operational level need to be revisited as their relevance may increase or diminish depending on the context. In both cases, the Scanner invites a reconsideration of the system the manufacturing company is attempting to transform and links circular strategies together in circular configurations: situations where two or more circular strategies work together (Blomsma et al., 2018).

The range of sectors used for the validation efforts - heavy machinery, electronics and furniture - points to the broad applicability of the Scanner for manufacturing companies from different sectors. However, the framework could be further strengthened by validation with a wider set of manufacturing companies, including those that (also) operate within the biocycle, or that provide dissipative products (e.g. paints, lubricants, cleaning agents and other chemicals).

Further work should address how the Scanner can be linked to the assessment of (combinations of) circular strategies and different implementation scenarios, such that in the early stages of innovation processes the impact on economic, environmental and social systems can be evaluated and actions implemented to minimise negative impact and maximise positive impact. It could furthermore be explored whether the framework has potential to address the lack of a common understanding between value chain actors, which is perceived as an obstacle for the implementation of CE (Machacek et al. 2017; Lapko et al. 2018). In addition to using the Scanner by itself, there is also a need for understanding how different classes of circular strategies frameworks (e.g. macro, meso, micro, nano, networked) can best be used together.

9. Summary and conclusion

With this paper, we have contributed to the development of support tools for CE oriented innovation, or COI and to enable the translation of the CE concept in practice by creating support for visioning for CE. The contribution of this paper is four-fold: a) it provides an example of a process of how a circular strategies framework can be developed for a specific business type with the ability to support COI processes, b) it proposes a circular strategies framework for the manufacturing context, with c) an accompanying set of definitions of circular strategies, and d) it provides an example of how such a framework can be used in the early stages of a COI process. Next, it will be discussed how each goal was achieved and what the implications are for academia and industry.

In support of the first goal - to provide an example of the development of a circular strategies framework - this paper used the lens of Design Research Methodology (Blessing and Chakrabarti, 2009). This answered the call for the more deliberate and systematic development of circular strategies frameworks that are fit for purpose, voiced in Niero and Hauschild (2017) and Blomsma (2018). With manufacturing companies as the focus, it provided an example of how academia and industry can work together following a transdisciplinary approach (Sakao and Brambila, 2018) in developing resonant frameworks for specific audiences. The systematic development approach followed in this paper can be adapted and further expanded upon for other business types or other innovation contexts.

The second goal was achieved through the provision of the Circular Strategies Scanner. This framework can be used as a tool in COI and provides practitioners in manufacturing with a way of contextualising the CE concept, mapping current CE initiatives, and generating ideas for increased circularity. The third contribution, the set of circular strategies definitions included in the framework, served to support the consolidation of CE terminology and bringing academic and practitioner terminology closer together (Reike et al. 2018; Meste and

Cooper 2017; Kalmykova et al., 2018). This was achieved through drawing on both academic and practitioner perspectives with regards to these definitions in the development process. Together, these two points mean that an important iteration on the framework provided by Potting and colleagues was made, which brings more precision to the framework and which customises it for the manufacturing context. With this, the framework has been transformed from analytical framework into an innovation tool.

The fourth goal was achieved through illustrating how the Circular Strategies Scanner can be used in the early stages of a COI process to create a shared vision. The examples provided are of its application within businesses (see section 6). As well as with these companies, the Scanner was used with the other manufacturing companies participating in the CIRCit project. Specifically, it was used in the early stages of the action research, which allowed for a clear vision to be developed and establishing a clear direction for the work that followed, as it clarified with what aim different business activities relevant for COI needed to be deployed, whether this involved sustainability assessment, business model innovation, product design, digital technology strategies, the creation of take-back systems or value chain design.

Equally the Scanner could be applied across businesses, but also between business and academia, and beyond. In these contexts, the Scanner can serve as a boundary object where the stakeholders can clearly identify their activities or influence on different business processes across the life cycle, also enabling the comparison of CE initiatives and sharing of best practices.

Acknowledgements

This article is one of the outcomes of the research project CIRCit (Circular Economy Integration in the Nordic Industry for Enhanced Sustainability and Competitiveness), which is part of the Nordic Green Growth Research and Innovation Programme (grant numbers: 83144) and funded by NordForsk, Nordic Energy Research, and Nordic Innovation. We would also like to thank the companies participating in the CIRCit project and the anonymous reviewers whose thoughtful feedback aided the development of this work.

CIRCit is a collaboration of:

Technical University of Denmark

Research Institutes of Sweden IVF

Norwegian University of Science and Technology

Innovation Center Iceland

Technology Industries of Finland

Appendix A

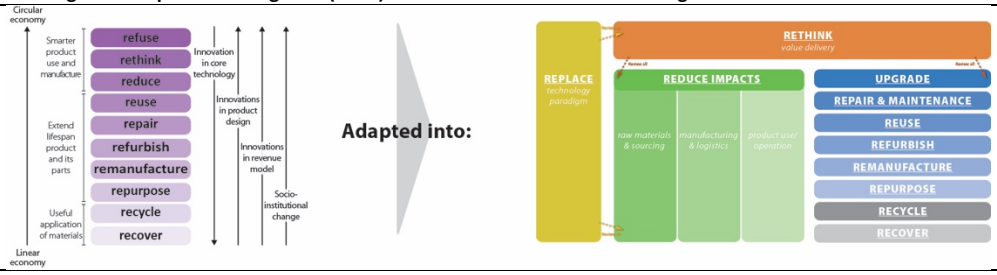
Overview of changes to adapt the Potting et al (2017) framework for the manufacturing context		
		
Major adaptations - changes in the structure of the framework		
#	In Potting et al (2017):	First version of Circular Strategies Scanner:
1	Circular strategies organised hierarchically: ranging from those that are considered more linear to those that are increasingly more circular.	Circular strategies are organised according to the business functions they apply to, in five main areas: *Replace*, *Rethink*, *Reduce Impacts* and two other operational process areas respectively containing end-of-use and end-of-life strategies
2	'Reduce' presented a single high-level strategy.	Specified into 'Reduce impacts' and the sub-categories of 'raw materials & sourcing,' 'manufacturing & logistics,' and 'product use/ operation.'
3	-	A visual structure consisting of three levels has been created to indicate the relationship of circular strategies, through the relative placement of the boxes containing the strategies, and the addition of arrows.
Medium adaptations - changes to the sub-groups or categories of the framework		
1	Inclusion of *Refuse* at the top of the hierarchy.	In the Circular Strategies Scanner, this strategy is understood as consisting of two sub-strategies and it was therefore split in two: *Refuse* (to abandon a practice altogether) and *Replace* (see Table 2). *Refuse* was subsequently not included in the framework, due to this framework targeting companies (see also Discussion section).
2	Contains the value driver: "Smarter product use and manufacture" for *Refuse*, *Rethink* and *Reduce*.	To refine this further, this value driver was split into "dematerialise/ combine functions" for *Replace*, "function & value proposition to market" for *Rethink*, and "improve circularity potential and efficiency" for *Reduce Impacts*.
3	Contains the value driver: "Extend lifespan of products and parts" for *Reuse*, *Repair*, *Refurbish*, *Remanufacture* and *Repurpose.*	To refine this further, this value driver was split in two to align with the end-of-use and end-of-life groupings as in line with Potting. As a result, *Upgrade*, *Repair & Maintenance* and *Reuse* are assigned the driver "Extending existing use-cycle," and *Refurbish*, *Remanufacture* and *Repurpose* are assigned the driver "Extending to new use-cycle."
Minor adaptations -- refinements in labels, definitions and the order of circular strategies		
1	Inclusion of *Recover*, as a strategy that refers to energy recovery through incineration, anaerobic digestion, pyrolysis.	The definition of *Recover* has been expanded to also include the recovery of biological nutrients and as such also covers such strategies as composting.
2	-	*Upgrade* was added to the framework to make explicit evolving quality and performance requirements of products.
3	*Reuse* comes before *Repair* in strategy order.	The order of *Reuse* and *Repair* was reversed, as Reuse that involves mere redistribution of products will – theoretically – maintain value to a higher degree with less added investment of resources, than redistribution that is also combined with repair activities.
4	Includes *Repair* as a circular strategy.	Repair was extended to also include maintenance, which is a common terminology in companies, and as such is indicated as *Repair & Maintenance* in the framework.

Table - This overview explains which changes were made to the Potting et al (2017) framework in order to adapt it to the manufacturing context. It gives a complete overview of the major, medium and minor adaptations.

Appendix B

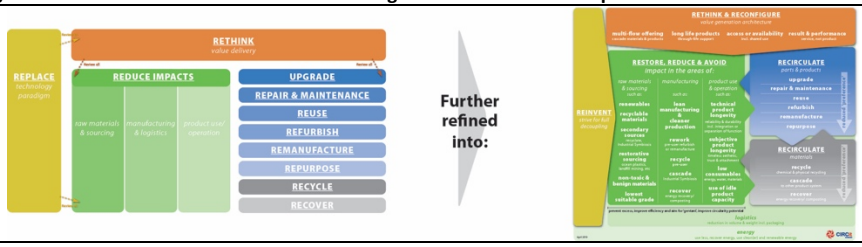
Overview of changes to refine the 1st version of Circular Strategies Scanner and develop the 2nd version		
		
Medium adaptations - changes to the sub-groups or categories of the framework		
#	First version of framework	Second version of Circular Strategies Scanner:
1	The process of *Logistics* featured alongside *Manufacturing*.	*Logistics* is assigned a separate area in the framework, to better reflect that it covers all the operational process areas.
2	-	*Energy* was added as a relevant layer. That is: circular strategies should be considered with the intent to reduce overall energy consumption, and use clean(er) and renewable sources wherever possible.
3	Featured the strategy *Reduce Impacts*.	Label of strategy was changed to *Restore, Reduce and Avoid* to more fully reflect the range of strategies relevant for raw materials and sourcing, manufacturing and product use and operation.
4		Explicit addition of relevant strategies in *Restore, Reduce & Avoid.* Such as restorative sourcing (i.e. re-mining from landfill or using ocean plastics), lean and cleaner production practices and using idle product capacity. *Cascade* was also included: it can occur as Industrial Symbiosis and either as a secondary source sourcing strategy, or as a way of managing the co- and byproducts from manufacturing.
5	No detail provided regarding Rethink & Reconfigure.	To clarify the framework's relationship business models aspects, detail was added to the Rethink & Reconfigure category. This was done by drawing on Bocken et al. (2016) and Tukker's (2004) and adding the four main categories of Multi-flow offering, Long-life products, Access or availability, and Result and performance.
6	No explicit place for product and process design.	Product and process design are explicitly acknowledged by including them as box between Rethink & Reconfigure and the operational process of Restore, Reduce & Avoid and the Recirculate parts, products & materials.
Minor adaptations - refinements in labels, definitions and the order of circular strategies		
1	Value drivers largely based on Potting et al. (2017).	Value drivers were further refined: for *Reinvent* it was changed to "strive for radical decoupling," and for *Rethink* to "aim for business innovation for circularity," and for *Restore, Reduce and Avoid,* to "prevent excess, improve efficiency and aim for 'gentani' and improve circularity potential."
2	Visual structure consisting of three levels has been created to indicate the relationship of circular strategies, through the relative placement of the boxes, and the addition of arrows.	Visual layering emphasised through depicting it using the visual metaphor of physical layers, which takes the form of drop shadows and arrows to indicate the relationship between the process areas. Hierarchical relationships indicated by a single arrow, trade-offs and synergies by bi-directional arrows.
3	No indication of hierarchy of end-of-use and end-of-life strategies	Arrows were added to indicate the (theoretically) preferred application order of these strategies.
4	Headings only applied for *Replace, Rethink* and *Reduce Impacts.*	For consistency, all five process areas are given headings. End-of-use processes are titled *Recirculate – parts & products* and end-of-life processes are titled *Recirculate – materials*.
5	-	*Cascade* was added to *Recirculate – materials*. This adds the distinction between recycling – i.e. those processes that keep material circulating at or near virgin levels of performance, and cascades – i.e. those processes that extend the life of materials through allowing for reduction or redefinition of performance characteristics.
6		Addition of descriptors to strategies to aid in clarifying the type of application. For example: recycling can take place at the manufacturing stage, where it involves re-entering waste from the manufacturing process back into the process: pre-user recycling. It can also take place post-user at the *Recirculate – materials* stage, in the form of chemical or physical (mechanical) recycling.
7	Featured the strategy label *Replace*.	*Replace* was changed to *Reinvent - strive for full decoupling*, to prevent confusion in relation the replacing harmful chemicals with less harmful or benign ones. Moreover, this term better conveys the transformative nature of this strategy.
8	Featured the strategy label *Rethink value delivery.*	Changed to *Rethink & Reconfigure value generation architecture.*

Table - This overview explains which changes were made to the first version of the framework in order to develop the second and final version. It gives a complete overview of the medium and minor adaptations. No major adaptations were made at this stage.

REFERENCES

Aguiñaga, E., Henriques, I., Scheel, C., Scheel, A., 2018. Building resilience: A self-sustainable community approach to the triple bottom line. J. Clean. Prod. 173, 186–196. https://doi.org/10.1016/j.jclepro.2017.01.094

Allwood, J.M., Ashby, M.F., Gutowski, T.G., Worrell, E., 2011. Material efficiency: A white paper. Resour. Conserv. Recycl. 55, 362–381. https://doi.org/10.1016/j.resconrec.2010.11.002

Biloslavo, R., Bagnoli, C., Edgar, D., 2018. An eco-critical perspective on business models: The value triangle as an approach to closing the sustainability gap. J. Clean. Prod. 174, 746–762. https://doi.org/10.1016/j.jclepro.2017.10.281

Bititci, U.S., Martinez, V., Albores, P., Parung, J., 2004. Creating and managing value in collaborative networks. Int. J. Phys. Distrib. Logist. Manag. 34, 251–268. https://doi.org/10.1108/09600030410533574

Blessing, L.T.M., Chakrabarti, A., 2009. DRM, a Design Research Methodology. Springer-Verlag, London.

Blomsma, F., Brennan, G., 2017. The Emergence of Circular Economy: A New Framing Around Prolonging Resource Productivity. J. Ind. Ecol. 21. https://doi.org/10.1111/jiec.12603

Blomsma, F., Kjaer, L., Pigosso, D., McAloone, T., Lloyd, S., 2018. Exploring Circular Strategy Combinations - Towards Understanding the Role of PSS, in: Procedia CIRP. https://doi.org/10.1016/j.procir.2017.11.129

Blomsma, F., 2018. Collective 'action recipes' in a circular economy – On waste and resource management frameworks and their role in collective change. J. Clean. Prod. 199, 969–982. https://doi.org/10.1016/j.jclepro.2018.07.145

Bocken, N.M.P., Antikainen, M., 2019. Circular Business Model Experimentation: Concept and Approaches, in: Dao, D., Howlett, R.J., Setchi, R., Vlacic, L. (Eds.), Sustainable Design and Manufacturing 2018. Springer International Publishing, Cham, pp. 239–250.

Bocken, N.M.P., de Pauw, I., Bakker, C., van der Grinten, B., 2016. Product design and business model strategies for a circular economy. J. Ind. Prod. Eng. 33, 308–320. https://doi.org/10.1080/21681015.2016.1172124

Boons, F., Howard-Grenville, J., 2009. The Social Embeddedness of Industrial Ecology. Edward Elgar Publishing Ltd, Cheltenham, UK.

Braungart, M., McDonough, W., 2002. Cradle to Cradle: Remaking the Way We Make Things, 1st ed. North Point Press, New York.

Breuer, H., Fichter, K., Freund, F.L., Tiemann, I., 2018. Sustainability-oriented business model development: principles, criteria and tools. Int. J. Entrep. Ventur. 10, 256. https://doi.org/10.1504/IJEV.2018.092715

Brown, P., Bocken, N., Balkenende, R., 2019. Why Do Companies Pursue Collaborative Circular Oriented Innovation? Sustainability 11, 635. https://doi.org/10.3390/su11030635

Chiappetta Jabbour, C.J., Sarkis, J., Lopes de Sousa Jabbour, A.B., Scott Renwick, D.W., Singh, S.K., Grebinevych, O., Kruglianskas, I., Filho, M.G., 2019. Who is in charge? A review and a research agenda on the 'human side' of the circular economy. J. Clean. Prod. 222, 793–801. https://doi.org/10.1016/j.jclepro.2019.03.038

Circle Economy, 2019. The Circularity Gap Report 2019.

Circle Economy, 2016. Master Circular Business with the Value Hill – Circle Economy.

Cullen, J.M., 2017. Circular Economy: Theoretical Benchmark or Perpetual Motion Machine? J. Ind. Ecol. 21, 483–486. https://doi.org/10.1111/jiec.12599

de Jesus, A., Antunes, P., Santos, R., Mendonça, S., 2018. Eco-innovation in the transition to a circular economy: An analytical literature review. J. Clean. Prod. 172, 2999–3018. https://doi.org/10.1016/j.jclepro.2017.11.111

den Hollander, M.C., Bakker, C.A., Hultink, E.J., 2017. Product Design in a Circular Economy: Development of a Typology of Key Concepts and Terms. J. Ind. Ecol. 21, 517–525. https://doi.org/10.1111/jiec.12610

EC (European Parliament and Council), 2008, Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain directives (Waste framework).

ECN (European Compost Network), 2018. European Compost Network ECN e.V. [WWW Document]. Organ. website. URL https://www.compostnetwork.info/about-ecn/ (accessed 10.25.18).

Ehrenfeld, J., Gertler, N., 1997. Industrial Ecology in Practice: The Evolution of Interdependence at Kalundborg. J. Ind. Ecol. 1, 67–79. https://doi.org/10.1162/jiec.1997.1.1.67

EMF (Ellen MacArthur Foundation), 2013. Towards the Circular Economy: Economic and business rational for an accelerated transition.

EMF (Ellen MacArthur Foundation), 2017. A NEW TEXTILES ECONOMY: REDESIGNING FASHION'S FUTURE. Isle of Wight.

EMF (Ellen MacArthur Foundation), 2015. Growth within: a circular economy vision for a competitive europe. https://doi.org/Article

Gispen, 2018. Circular furniture [WWW Document]. Co. website. URL https://www.gispen.com/en/circular-economy/circular-furniture-circular-economy (accessed 10.25.18).

GreenBiz, 2014. How Toyota uses gentani to optimize performance and cut waste [WWW Document]. Organ. website. URL https://www.greenbiz.com/article/how-toyota-uses-gentani-optimize-performance-and-cut-waste (accessed 10.25.18).

Guzzo, D., Trevisan, A.H., Echeveste, M., Costa, J.M.H., 2019. Circular Innovation Framework: Verifying Conceptual to Practical Decisions in Sustainability-Oriented Product-Service System Cases. Sustainability 11, 3248. https://doi.org/10.3390/su11123248

Haas, W., Krausmann, F., Wiedenhofer, D., Heinz, M., 2015. How Circular is the Global Economy?: An Assessment of Material Flows, Waste Production, and Recycling in the European Union and the World in 2005. J. Ind. Ecol. 19, 765–777. https://doi.org/10.1111/jiec.12244

Hoffman, A.J., 2003. Linking Social Systems Analysis To The Industrial Ecology Framework. Organ. Environ. 16, 66–86. https://doi.org/10.1177/1086026602250219

Ijomah, W., 2009. Addressing decision making for remanufacturing operations and design-for-remanufacture. Int. J. Sustain. Eng. 2, 91–202. https://doi.org/10.1080/19397030902953080

Ijomah, W.L., 2002. A model-based definition of the generic remanufacturing business process 420. https://doi.org/10026.1/601

Inditex, 2016. TOWARDS A CIRCULAR ECONOMY [WWW Document]. Co. website. URL http://static.inditex.com/annual_report_2016/en/our-priorities/commitment-to-the-excellence-of-our-products/towards-a-circular-economy.php (accessed 10.2.18).

Interface, 2017. The ReEntryTM Carpet Recycling Program [WWW Document]. URL http://www.interface.com/APAC/en-AU/about/mission/ReEntry-en_AU (accessed 8.11.17).

Interface, 2018. A Look Back: Interface's Sustainability Journey [WWW Document]. Co. website. URL http://www.interface.com/US/en-US/campaign/climate-take-back/Sustainability-A-Look-Back-en_US (accessed 9.25.18).

Johannsdottir, L., 2014. Transforming the linear insurance business model to a closed-loop insurance model: a case study of Nordic non-life insurers. J. Clean. Prod. 83, 341–355. https://doi.org/10.1016/j.jclepro.2014.07.010

Kalmykova, Y., Sadagopan, M., Rosado, L., 2018. Circular economy – From review of theories and practices to development of implementation tools. Resour. Conserv. Recycl. 135, 190–201. https://doi.org/10.1016/j.resconrec.2017.10.034

Konecranes, 2018. Circular economy [WWW Document]. Co. website. URL https://www.konecranes.com/about-konecranes/corporate-responsibility/circular-economy (accessed 10.25.18).

Kravchenko, M., McAloone, T.C., Pigosso, D.C.A., 2019. Implications of developing a tool for sustainability screening of circular economy initiatives. Procedia CIRP 80, 625–630. https://doi.org/10.1016/j.procir.2019.01.044

Lapko, Y., Trianni, A., Nuur, C., Masi, D., 2018. In Pursuit of Closed-Loop Supply Chains for Critical Materials: An Exploratory Study in the Green Energy Sector. J. Ind. Ecol. https://doi.org/10.1111/jiec.12741

Levi Strauss & Co., 2015. TO INFINITY AND BEYOND: HOW WE'RE EMBRACING THE CIRCULAR ECONOMY [WWW Document]. Co. website. URL https://levistrauss.com/unzipped-blog/2015/07/21/embracing-the-circular-economy/ (accessed 10.2.18).

Lindkvist, M., Baumann, H., 2014. A Review of Social Science in Five Industrial Ecology Journals. Gothenburg, Sweden.

Machacek, E., Richter, J., Lane, R., 2017. Governance and Risk–Value Constructions in Closing Loops of Rare Earth Elements in Global Value Chains. Resources 6, 59. https://doi.org/10.3390/resources6040059

Mendoza, J.M.F., Sharmina, M., Gallego-Schmid, A., Heyes, G., Azapagic, A., 2017. Integrating Backcasting and Eco-Design for the Circular Economy: The BECE Framework. J. Ind. Ecol. 21, 526–544. https://doi.org/10.1111/jiec.12590

Mendoza, J.M.F., Sharmina, M., Gallego-Schmid, A., Heyes, G., Azapagic, A., 2017. Integrating Backcasting and Eco-Design for the Circular Economy: The BECE Framework. J. Ind. Ecol. 21, 526–544. https://doi.org/10.1111/jiec.12590

Mestre, A., Cooper, T., 2017. Circular Product Design. A Multiple Loops Life Cycle Design Approach for the Circular Economy. Des. J. 20, S1620–S1635. https://doi.org/10.1080/14606925.2017.1352686

Mistra Future Fashion, 2018. Sustainable Fashion [WWW Document]. Organ. website.

Mitsubishi Electric - Mitsubishi Elevator Europe, 2018. M-use - van bezit naar gebruik (from ownership to use) [WWW Document]. URL https://www.mitsubishi-liften.nl/m-use/

Moraga, G., Huysveld, S., Mathieux, F., Blengini, G.A., Alaerts, L., Van Acker, K., de Meester, S., Dewulf, J., 2019. Circular economy indicators: What do they measure? Resour. Conserv. Recycl. 146, 452–461. https://doi.org/10.1016/j.resconrec.2019.03.045

Moreno, M., De los Rios, C., Rowe, Z., Charnley, F., 2016. A Conceptual Framework for Circular Design. Sustainability 8, 937. https://doi.org/10.3390/su8090937

Murray, A., Skene, K., Haynes, K., 2017. The Circular Economy: An Interdisciplinary Exploration of the Concept and Application in a Global Context. J. Bus. Ethics 140, 369–380. https://doi.org/10.1007/s10551-015-2693-2

Niero, M., Hauschild, M.Z., 2017. Closing the Loop for Packaging: Finding a Framework to Operationalize Circular Economy Strategies. Procedia CIRP 61, 685–690. https://doi.org/10.1016/j.procir.2016.11.209

Nilsson-Lindén, H., Baumann, H., Rex, E., 2019. LCM development: focusing on the LC promoters and their organizational problem-solving. Int. J. Life Cycle Assess. 24, 297–309. https://doi.org/10.1007/s11367-018-1523-z

Nußholz, J., 2017. Circular Business Models: Defining a Concept and Framing an Emerging Research Field. Sustainability 9, 1810. https://doi.org/10.3390/su9101810

Parkinson, H.J., Thompson, G., 2003. Analysis and Taxonomy of Remanufacturing Industry Practice. J. Process Mech. Eng. 217, 243–256. https://doi.org/10.1243/095440803322328890

Pauli, G., 2010. The Blue Economy: 10 years, 100 innovations, 100 million jobs. Paradigm Publications.

Pearce, C.L., Ensley, M.D., 2004. A reciprocal and longitudinal investigation of the innovation process: the central role of shared vision in product and process innovation teams(PPITs). J. Organ. Behav. 25, 259–278. https://doi.org/10.1002/job.235

Pieroni, M.P.P., Blomsma, F., McAloone, T.C., Pigosso, D.C.A., 2018. Enabling circular strategies with different types of product/service-systems. Procedia CIRP 73, 179–184. https://doi.org/10.1016/j.procir.2018.03.327

Pieroni, M.P.P., McAloone, T.C., Pigosso, D.C.A., 2019. Business model innovation for circular economy and sustainability: A review of approaches. J. Clean. Prod. 215, 198–216. https://doi.org/10.1016/j.jclepro.2019.01.036

Plastic Ocean, 2018. #RethinkPlastic [WWW Document]. Organ. website. URL https://plasticoceans.org/ (accessed 10.25.18).

Potting, J., Hekkert, M.P., Worrell, E., Hanemaaijer, A., 2017. Circular economy: measuring innovation in the product chain. The Hague, The Netherlands.

Rashid, A., Asif, F.M.A., Krajnik, P., Nicolescu, C.M., 2013. Resource conservative manufacturing: An essential change in business and technology paradigm for sustainable manufacturing. J. Clean. Prod. 57, 166–177. https://doi.org/10.1016/j.jclepro.2013.06.012

Reike, D., Vermeulen, W.J.V., Witjes, S., 2018. The circular economy: New or Refurbished as CE 3.0? — Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options. Resour. Conserv. Recycl. 135, 246–264. https://doi.org/10.1016/j.resconrec.2017.08.027

Ricoh, 2018. “Vision—The Comet CircleTM” [WWW Document]. Co. website. URL https://www.ricoh.com/environment/management/concept.html (accessed 9.25.18).

Rosa, P., Sassanelli, C., Terzi, S., 2019. Towards Circular Business Models: A systematic literature review on classification frameworks and archetypes. J. Clean. Prod. 236, 117696. https://doi.org/10.1016/j.jclepro.2019.117696

Saavedra, Y.M.B., Barquet, A.P.B., Rozenfeld, H., Forcellini, F.A., Ometto, A.R., 2013. Remanufacturing in Brazil: Case studies on the automotive sector. J. Clean. Prod. 53, 267–276. https://doi.org/10.1016/j.jclepro.2013.03.038

Saidani, M., Yannou, B., Leroy, Y., Cluzel, F., 2017. How to Assess Product Performance in the Circular Economy? Proposed Requirements for the Design of a Circularity Measurement Framework. Recycling 2, 6. https://doi.org/10.3390/recycling2010006

Saidani, M., Yannou, B., Leroy, Y., Cluzel, F., Kendall, A., 2019. A taxonomy of circular economy indicators. J. Clean. Prod. 207, 542–559. https://doi.org/10.1016/j.jclepro.2018.10.014

Sakao, T., Brambila-Macias, S.A., 2018. Do we share an understanding of transdisciplinarity in environmental sustainability research? J. Clean. Prod. 170, 1399–1403. https://doi.org/10.1016/j.jclepro.2017.09.226

Sirkin, T., Houten, M. ten, 1994. The cascade chain. A theory and tool for achieving resource sustainability with applications for product design. Resour. Conserv. Recycl. 10, 213–276. https://doi.org/10.1016/0921-3449(94)90016-7

Stahel, W., 2006. The Performance Economy, 2nd ed. Palgrave MacMillan.

Star, S.L., Griesemer, J.R., 1989. Institutional Ecology, `Translations' and Boundary Objects: Amateurs and Professionals in Berkeley's Museum of Vertebrate Zoology, 1907-39. Soc. Stud. Sci. 19, 387–420. https://doi.org/10.1177/030631289019003001

The Ocean Cleanup, 2018. The largest cleanup in history [WWW Document]. Organ. website. URL https://www.theoceancleanup.com/ (accessed 10.25.18).

Thierry, M., Salomon, M., Van Nunen, J., Van Wassenhove, L., 1995. Strategic Issues in Product Recovery Management. Calif. Manage. Rev. 37, 114–136. https://doi.org/10.2307/41165792

Tukker, A., 2004. Eight types of product–service system: eight ways to sustainability? Experiences from SusProNet. Bus. Strateg. Environ. 13, 246–260. https://doi.org/10.1002/bse.414

Upadhyay, A., Akter, S., Adams, L., Kumar, V., Varma, N., 2019. Investigating “circular business models” in the manufacturing and service sectors. J. Manuf. Technol. Manag. 30, 590–606. https://doi.org/10.1108/JMTM-02-2018-0063

Weissbrod, I., Bocken, N.M.P., 2017. Developing sustainable business experimentation capability – A case study. J. Clean. Prod. 142, 2663–2676. https://doi.org/10.1016/j.jclepro.2016.11.009

WssTP, 2015. The role of water in the circular economy [WWW Document]. in: Vlakwa. URL https://www.vlakwa.be/en/publications/news/nieuwsbericht-en/news/new-ec-circular-economy-package-and-water/ (accessed 10.2.18).