CRADLE-TO-CRADLE FRONT-END INNOVATION: MANAGEMENT OF THE DESIGN PROCESS

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B. Synonyms (*if applicable*)

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C. Definitions

Cradle-to-cradle

Cradle-to-cradle (C2C) is both a design and production approach that is used when targeting zero emissions and eco-efficiency (Braungart et al., 2007). The target of eco-efficiency and zero emissions is also aimed to minimize possible negative consequences of the production and consumption of the products. The C2C design approach offers a framework for creating products and production systems in various industrial sectors. In the C2C approach, the product design team needs to establish an eco-effective nutrient management plan that is used to describe and manage all material flows between all the actors in the production processes.

Front-end innovation

The front-end innovation (FEI) phase comes before the more formal and well-structured new product and process development processes (Koen et al., 2001). At this stage, the innovation process can be chaotic due to unstructured and unpredictable activities that the product design team needs to tackle in the process. The unique characteristics in this phase are opportunity identification, analysis, and idea generation, in addition to an experimental approach which make this phase difficult to plan (Koen et al., 2001). In the FEI phase, there are numerous critical decisions that need to be made regarding the product and production processes that have an impact on the whole life cycle of the product. The front-end innovation (FEI) phase is crucial when designing a new product's sustainability (Eling, 2020). This is especially important in the case of C2C products where the scope of the product's life cycle is more far reaching than for a conventional product. In addition to the product concept, the project set-up needs to be planned in this phase.

Introduction

In abstract terms, innovation processes are more or less complex problem-solving procedures. In particular, the early phases – the so-called “fuzzy-front-end” (ideation and conception) - are complex and difficult to structure, very much depending on the degree of innovation of a project (architectural/radical versus incremental) (Herstatt and Verworn, 2004; Koen et al., 2001; Reid and De Brentani, 2004). The higher the degree of innovation, the less a firm or an innovator can draw back on experience and knowledge that would support the rapid implementation of the project. But it is not only the degree of innovation in terms of technical and/or market novelty that plays a role here. Likely the use of new materials, manufacturing processes or the cooperation with yet unknown suppliers poses great challenges for innovating companies. The needed learning and adaptation processes require time, new competences, and the development of new routines, which may conflict with expected or even promised project results (quality, time, costs). This again can lead to conflicts between team members in innovation teams as well as among internal and external stakeholders including customers.

Particularly firms that are aiming to adapt their innovation processes to the requirements of a circular economy and even more concretely to the cradle-to-cradle (C2C) certification requirements (Braungart et al., 2007) typically face multiple challenges. Especially firms that have not yet gained any experience with the challenges of implementing C2C into their innovation work are confronted with high complexity. They need to make critical decisions very early in the C2C innovation process about, for example, the selection of input materials that are harmless to humans and nature, appropriate and even certified for manufacturing, new or adapted production infrastructures and processes, non-hazardous packaging and product presentations as well as recycling processes that allow the company to recycle products as well as packaging in biological or technical cycles (Braungart et al., 2007). The associated changes and process-related conversions require not only appropriate knowledge in a preferably diverse innovation team but also intensive coordination of all affected functional areas in the company as well as external partners (Drabe and Herstatt, 2016).

When comparing multidisciplinary, interdisciplinary, and transdisciplinary collaboration approaches, the complexity in C2C projects matches the best a transdisciplinary approach (Lang et al., 2012; Schaltegger et al., 2013). The multidisciplinary approach focuses on two or more disciplines that all provide their unique perspective to a problem, however, it does not result in collaboration activities across the disciplines. In an interdisciplinary approach, two or more disciplines are combined to a new level of integration, and the target of the research is commonly defined, but practitioners are not included as partners in the research. However, in a transdisciplinary approach, the efforts of multiple disciplines together form a more comprehensive approach that also involves societal actors and practitioners, and the resulting output can be a solution that is an integration of the disciplines’ inputs and contributions (Schaltegger et al., 2013).

Transdisciplinary collaboration necessitates cooperation between academic partners and practitioners to develop solutions that are practical and relevant for the current world we live in. The collaboration should be participatory and enable many kinds of partnerships and ways of cooperation (Schaltegger et al., 2013). Cross-functional teams with members with diverse backgrounds have more resources to rely on when generating, developing, combining, and evaluating different ideas. The diversity in the team stimulates more creativity and effective decision making which ensures that the solutions developed are more comprehensive and of higher quality (Bassett-Jones, 2005).

Sustainability-oriented innovation management and C2C innovation processes

Environmental or sustainability-oriented innovations are conducted by firms that create new ideas, products, and processes, and contribute to the reduction of environmental burdens and ecologically specified sustainability targets (Rennings, 2000). Due to the complexity of the environmental problems, sustainability-oriented innovation is more challenging than other types of innovation (Hall and Vredenburg, 2003).

Schmitt and Hansen (2017a) have applied the absorptive capacity theory to analyze the knowledge management processes in C2C innovation processes. They found that focal firms collaborate with their value chain and institutional partners which enables the building of inter-organizational learning and knowledge management processes between the individuals in the teams. Schmitt and Hansen (2017a) focused on the assimilation and application phases of the absorptive capacity process, however, in the identification phase, in the very initial phases of the C2C innovation process, there are needs for initial collaboration with stakeholders. The identification phase can also be linked to the fuzzy front-end of the C2C innovation process, because that is when team members in focal firms are trying to understand how to solve problems with C2C principles, and thus are focusing on ideating and conceptualizing initial solution options and looking for new relevant stakeholders. In the identification phase, the diversity in the background of the team members becomes critical, as more knowledge and competences are required to solve the full-life cycle of a product design from a C2C perspective. In addition to the product design, the team needs to define the production process, product service, possible needs for changes in organizational routines and the development of a C2C business model.

In the case of C2C projects, the very formal and strict C2C certification process requires that the certifying firm collaborates with all its value chain partners which results in a very complex and demanding C2C innovation process (Drabe and Herstatt, 2016; Smits et al., 2016). For this reason, this earlier research has found that the individual level interactions between team members in the firm and with external partners are crucial for the C2C innovation process to get all the required external information and knowledge. The C2C product innovation and implementation are part of a learning process among the teams involved (Drabe and Herstatt, 2016).

Fuzzy front-end innovation

In the innovation literature, the process of innovation and the output from the innovation process are differentiated (Utterback, 1971). When studying the process of innovation, the focus is on the ways in which innovating is conducted, internally and externally on the individual, team, organizational and inter-organizational levels. The fuzzy front-end of sustainability-oriented innovations has not yet been specifically addressed and covered in the literature from the perspective of the process of the innovation. Bocken et al. (2014) have analyzed front-end eco-innovation approaches and have mapped the following skills required in the teams: creativity skills, engineering skills, environmental knowledge, design skills, and project management. The management of sustainability-oriented innovation has so far focused on product innovations and closing loops of product life cycles, for example, cradle-to-cradle (Braungart et al., 2007), the full product life cycle (Hansen et al., 2009), or circular innovation (Bocken et al., 2016). In the development of sustainable products, not only the product innovation, but also the production process, product service, as well as business model innovation is needed for the commercialization of a sustainable product. Thus, sustainability-oriented product innovation also requires new production processes, organizational routines and business model changes (Hansen et al., 2009) as well as new approaches to understanding the actual process of innovation.

The most critical decisions in the FEI phase for the sustainability of a new product concept concern the target market, technology used, and form of the product or solution. To ensure the viability of the created products on the markets, the products need to still fulfil the traditional project requirements of economic sustainability (Eling, Griffin, & Langerak, 2016) thus the entrepreneurial effort is required for creating a viable business with the product on the current markets. When creating a new C2C product concept, the decision-making process is very challenging. Thus, in an innovation team there is need for diverse knowledge from different disciplines and versatile understanding on multiple levels (Eling & Herstatt, 2017). This will ensure that the team is able to innovate solutions that enable systemic level changes and technological transition to a more sustainable society (Geels, 2005).

When firms want to develop their existing products so that they become truly sustainable, the challenges they face can be associated with commercialization of radical new products, which also require a totally new approach and new learning in the firms, even on the top management level. An intrapreneurial approach in a firm allows exploration and business experimentation, collaboration with new stakeholders that know the sustainability challenges in the markets and ensures readiness for firms to develop their business models to be more in line with the requirements of a circular economy (Wicki and Hansen, 2016).

Transdisciplinary collaboration in C2C development teams

Earlier research indicates that the circular or C2C and conventional innovation processes differ greatly regarding the level of required cooperation in and out of an individual firms' value chain (Drabe and Herstatt, 2016). This sets specific requirements on the competences in the team for handling new knowledge and information from different external sources (Roome and Louche, 2016). Natural and healthy environmental ecosystems are complex systems of living things, that need to be considered when designing products and solutions with a long-term perspective (McDonough et al., 2003). The diversity in nature offers ideas and models for humans to mimic. Diversity in design helps to create optimal sustainable design solutions that are suitable for specific local natural systems. In the implementation of C2C products and solutions that are locally suitable, the team also needs diversity that enables various kinds of understanding of the environmental ecosystem as well as the engineering and technical possibilities.

The need for close collaboration among different stakeholders in the C2C innovation process stresses the importance of a well-functioning innovation network. C2C innovation requires decision making on various levels in the innovation network, as the product designers of C2C products do not have the mandate to decide on changes required in the closed loop C2C production systems (Bakker et al., 2010). Firms targeting to implement a closed loop production system with C2C innovation require a tight connection and close network with their stakeholders, including suppliers and partners, with a long-term strategic objective and commitment to C2C, which requires open and trustworthy communication (Schmitt & Hansen, 2017b).

In the case of sustainability-oriented innovations, there are multiple stakeholders that need to be heard, for example, in the supply chain, suppliers and customers, because the solutions need to consider various environmental challenges. This requires a special set of dynamic capabilities in the C2C team and the management level so that firms and organizations can constantly identify, integrate, and control the required resources to create value in a changing environment (Castiaux, 2012). Firms that have dynamic capabilities are highly entrepreneurial, and thus are able to operate in changing conditions in business ecosystems, in addition, they are able to influence their business ecosystem through innovation and collaboration with their stakeholders and other firms and organizations (Teece, 2007). The microfoundations of dynamic capabilities defined by Teece (2007) include specific skills, processes, organizational structures, decision making rules, and disciplines. On that basis, recently developed term collaborative dynamic capabilities highlight those specific corporate capabilities, which enable to successfully orchestrate strategic collaboration within and outside the company (Kodama, 2018). Innovation can also be considered as a crucial part of the entrepreneurial process as well as a means for achieving business success (Drucker, 1985). With the urgent need for sustainable development to deal with the environmental and societal challenges in the current world, firms are required to discover new business opportunities and thus need to have an entrepreneurial approach when exploring new ideas.

Factors that have been found to have an impact on the creativity and collaboration in teams include trust, a strong team spirit, some common commitment, leadership with principles, an inspirational target, a results-driven and focused organization, possibility to participate in decision-making, support and recognition, and possibility to change roles and ways of working (Isaksen and Lauer, 2002). The significance of a results-driven approach for tackling environmental problems also has an influence on team behavior (Rossi, et al., 2006). It has been found that the environmental training of employees positively effects the teamwork, which, in addition to the level of the managers' environmental training, can lead to a greater environmental performance of a firm (Daily et al., 2012).

Extending the C2C product engineering and innovation process to wider contexts

The C2C design approach offers conceptually a distinctly different way of thinking than the prevailing industrial system design perspectives (McDonough et al., 2003). The material flows that enable a C2C like system produced by renewable energy sources can help to form regenerative closed loop cycles that are safe to humans and the environment, thus contributing to circular economy targets. The C2C product design is one of the first product design principles that has also generated a product certification standard for a circular economy (Braungart et al., 2007). This product certification standard helps firms in the C2C innovation and implementation process. In the C2C approach, the biological and technical loops are separated, and the certification requires that the materials can be cycled and the health effects of the materials are verified to eliminate hazardous substances, in addition to water stewardship, use of renewable energies, and social fairness. Recent research indicates that the implementation of voluntary sustainability standards such as the C2C product certification standard can pose significant challenges for firms (Smits et al., 2019). Factors impacting the implementation of a C2C certification include, for example, stakeholders' and teams' varying motives to adopt the design principles as well as their experiences gained in earlier certifications. Smits et al. (2019) call for more research on the intra-firm dynamics impacting voluntary sustainability standards implementation, as well as on the decision making among leadership as well as styles of employee involvement.

McDonough, Braungart, Anastas, and Zimmerman (2003) have defined 12 principles of green engineering to C2C design that guide in the optimization of products, processes, and systems and address the main issues that need to be taken into account in the C2C innovation process (See Appendix A. List of 12 Principles of Green Engineering). However, these principles tackle the "what" question of the actual product design, not the "how" question that would describe the product design team's ways of working. The C2C implementations require investments in time, capital, or other resources, including human resources, and the greatest returns in many cases result from redefining the customer problems so that there is a C2C solution to it (McDonough et al., 2003).

Management of product development at the front-end of the C2C innovation process

When a firm sets a vision for C2C development, the top management team needs to initiate the setting up of the team. The composition of the team can be refined based on several iterations with different team set-ups as the team works on exploring and reinventing cradle-to-cradle solutions. A well-functioning and creative C2C design team benefits from including other roles than design engineers, so that team members can work together with a transdisciplinary approach by exploring and experimenting with new stakeholders highly complex solution options in the fuzzy front-end innovation phase. This also ensures that later the actual testing and implementation phases will be more successful. When analyzing employment in the sectors of circular economy, Burger et al. (2019) found no particular level of education or specific set of skills intrinsic to a circular labour market, but rather highlighted a high degree of diversity, both in terms of education and skills, as of a prime importance.

The C2C framework and principles of green engineering designed for engineering teams (McDonough et al., 2003) require a supporting network in other parts of firms' organizations and among stakeholders who are willing to assist in the implementation and possibly adjust their own processes to any changes needed to the product design or production process. The stakeholders in large scale C2C projects may include such parties as investors, top managers, sales and marketing personnel who do not have an engineering background and who do not understand the technical details of the green engineering principles, however, they are important for the successful implementation of the projects. When the application of the 12 principles of green engineering (listed in figure 1 below) in C2C projects can be also supported by stakeholders with a non-engineering background, the long-term target of designing C2C products, services and systems for commercial use can be better ensured.

The C2C design principles defined by Braungart, et al. (2007) focus on product design practices that guide on the development of systems that enable positive economic, environmental, and social goals. The design principles offer guidance for designing products and industrial processes with a focus on material flows and understanding the biological and technical metabolisms. The stepwise design strategy has been targeted for businesses so that they can implement the transition of their business from a level of eco-efficiency to a higher level of eco-effectiveness in their product design. Eco-efficiency is associated with the implementation of internal company processes that enable to do more with less resources and causing less harm, and thus increasing value while at the same time reducing resources and pollution. Eco-effectiveness goes beyond this and focuses more on the development of products and production systems that can maintain the quality of materials through multiple use cycles. In ideal situations, companies combine eco-efficiency with eco-effectiveness to design products for the circular economy and circular industrial systems (McDonough and Braungart, 2002).

The C2C approach can be used to implement the transformation of a company to an eco-effective production system according to a five-step process. The C2C approach offers a way to extend the standard life cycle assessment (LCA) approach for creating eco-effective products and processes according to the C2C design steps. The process starts with the removal of undesirable substances and reinventing products. The reinvention requires that designers reconsider how the product could optimally fulfill the user needs and at the same time also take into account the sustainability of ecological and social systems. More specifically, the C2C design steps are: Step 1: Free of toxicological and eco-toxicological substances; Step 2: Personal preferences on substances that should be included in the product; Step 3: The passive positive list on the basis of a systematic assessment of each ingredient in a product; Step 4: The active positive list is created on the basis of the optimization of the passive positive list; Step 5: Reinvention of the relationship of the product with the customer (Braungart, et al. 2007).

The reinvention is a crucial step for tackling issues in the linkages between the ecological, social, and economic systems in order to enable the biological and technical metabolisms beyond the current product and service forms (Braungart, et al. 2007). The target of the Step 5 is to create and reinvent products as services to meet the requirements of customers in addition to social and ecological systems. To ensure that the reinvented products meet customer or consumer needs, many design approaches recommend starting by considering the customer needs in the initial phase of the innovation process. For example, in Design Thinking the innovation process starts by learning what customers want and need by direct observation, and how they assess the packaging, marketing, and support for products and services (Brown, 2008). The Design Thinking approach includes six phases: understand, observe, define, ideate, prototype and test. The team is an important resource in the process, for example, in the first phase of understanding, the focus is on the teamwork and how the team members together collect and seek information to understand a problem from different perspectives (Daniel, 2016).

The development of new circular economy business models for manufacturing firms also requires re-thinking of partnerships and reinventing new collaborative forms of cooperation to create business models that could also enable new ways of implementing remanufacturing processes (Lieder and Rashid, 2016). The collection and processing of complex data knowledge necessitates the transfer of additional knowledge that helps to get a holistic view of the solution on a systemic level. This also requires that firms and organizations integrate knowledge and experiences on existing products and processes in the innovation process. In addition, early stage consumer or customer involvement is crucial for succeeding on the markets with sustainable innovations (Hall and Kerr, 2003; Heiskanen et al., 2005). Improvement is still needed in the level of knowledge and awareness of the circular economy and its demands, for example, related to product design, among producers, firms and consumers in Europe specifically, as the European policies consider producer and consumer responsibility to be important in the implementation of the circular economy (Ghisellini et al., 2016).

Design for Environment

The main principle of the Design for Environment (DfE) approach is to integrate environmental perspectives in the early phases of a product and process design, while also considering the firms' technological landscape and organizational relationships (Allenby, 1994). This wide perspective of the whole business ecosystem as well as the natural ecosystem in which the firms operate encompasses a holistic view for sustainable businesses. The literature referring to DfE refer to an environmentally conscious approach of minimizing the negative environmental impacts of products during their life cycle, including recycling and reuse of a product (Hsu et al., 2013) as well as process design (Mishra and Napier, 2015; Jackson et al., 2016).

One of the earlier mappings of environmentally conscious business practices and management has been presented by Sarkis (1998). The model presented by him takes into account the linkages on the system and hierarchical levels, thus mapping the decisions and environmental factors in environmentally conscious business practices. One of the components in the model is the DfE, the other four components are: Life Cycle Analysis (LCA), Total Quality Environmental Management (TQEM), green supply chain and ISO 14001 Environmental Management Systems requirements. According to Sarkis (1998), the DfE philosophy entails the need to integrate environmental requirements in the early phases of a product or process design (Sarkis, 1998). These requirements include such functionality perspectives as recyclability, reuse, disassembly as well as disposal. However, Sarkis states as limitations for the model the following decision factors concerning strategic drivers of firms that are not included in the model but should be included in environmentally conscious business practices: cost, flexibility, and operational requirements. These missing elements are specifically required for building and implementing a more long-term vision and strategy that are aligned with all the environmental requirements and for guiding product design teams following the C2C principles.

The DfE process for product development entails 7 steps that can be divided into 5 different process phases in the product development process (Ulrich and Eppinger, 2011). In the 1) Product planning phase, the DfE agenda should be defined for the firm. In the 2) Conceptual Development phase, the potential environmental impacts are to be identified and the detailed DfE guidelines for the specific industrial sector should be decided. The 3) System-Level Design phase focuses on the application of the DfE guidelines to the initial product design. In the 4) Detail Design phase, the environmental impacts of the designed product are assessed and checked to refine the design and compare it to the actual DfE objectives in the DfE guidelines. Finally, in the 5) Process Improvement phase, the design team should go through the past project and its results to assess how the firm's processes could be improved for future DfE projects.

Front-end C2C innovation project management

The key competencies required in organizations and firms in their transition from eco-efficiency to eco-effective system are collaboration and co-ordination as well as a holistic system design thinking. When a firm fosters a culture that looks for new opportunities outside their existing value chain, they can better innovate. The capability to collaborate with different kinds of stakeholders and partners outside their current value chain ensure companies better chances to improve their sustainability performance and also learn new capabilities and acquire critical new knowledge from their stakeholders (Fernando and Evans, 2016). The Sustainability Mindset developed by Kassel, Rimanoczy, and Mitchell (2016) offers a transdisciplinary model for integrating the different perspectives from management ethics, entrepreneurship education, environmental studies, and systems thinking, however, this model focuses mainly on the manager level, thus the link to the actual implementation and product design is missing in concrete terms.

Based on the need to fully understand C2C design problems from a transdisciplinary perspective, the front-end C2C innovation process for new products and services could already start by the reinvention step that is listed as the 5th step in the C2C design principles. This requires that the project team works with a transdisciplinary perspective and collaborates with a wide variety of stakeholders and other roles in addition to product design engineers already at the beginning of the fuzzy front-end innovation phase. For example, in firms, the C2C product design team needs to get input from top management, sales & marketing, customer service, manufacturing, supplier management, logistics teams, in addition to other stakeholders, consumers, customers and partners in the value chain. Team diversity should be promoted in organizations to boost the creative performance and promote an innovating work environment (Ruscio et al., 1995).

The collaboration in the C2C innovation process can enable learning processes between the focal firm and its stakeholders and value chain partners resulting in new knowledge and innovation (Schmitt and Hansen, 2017b). In the C2C innovation process, suppliers in the value chain are also required to be receptive to possible changes and be prepared to develop their products and process to fulfill C2C quality requirements, which can result in complex search processes for entirely new ways of working. With reference to the absorptive capacity theory (Cohen and Levinthal, 1990), in the identification phase a firm working on C2C design initially finds, recognizes, and understands new knowledge via exploratory learning (Schmitt and Hansen, 2017b).

Fahnenmüller et al. (2018) point out that the management of C2C projects should be managed actively, with several divergent and convergent points during the process where specific competences are added to the product development team from the outside depending on the disciplinary tasks during one or another stage. This enables the team to collaborate with new stakeholders and reinvent, explore, and experiment with different product concepts. The outcome of the fuzzy front-end C2C innovation process is thus a tested team set-up created in the FEI iteration process that has an initial understanding of the possible cross-functional processes and transdisciplinary product concepts to be tested in the following phases of the C2C innovation process.

Based on the literature above, the authors present a framework for the management of the C2C product development in the fuzzy front-end of the C2C innovation process. The vision from the top management team in the organization set towards the development C2C products stands as a starting point for the project. The DfE process for product development defined by Ulrich and Eppinger (2011) describes what specific steps should be taken at the fuzzy front-end while following the principles of green engineering (McDonough et al., 2003) that act as a key integral part of any to C2C project. The C2C design steps described by Braungart et al. (2007) then explain how each step in the present process should be carried out and what aim at every step should be achieved on the product level. The figure below shows how the Design for Environment process, Principles of Green Engineering and C2C Design principles are connected to each other (Figure 1).

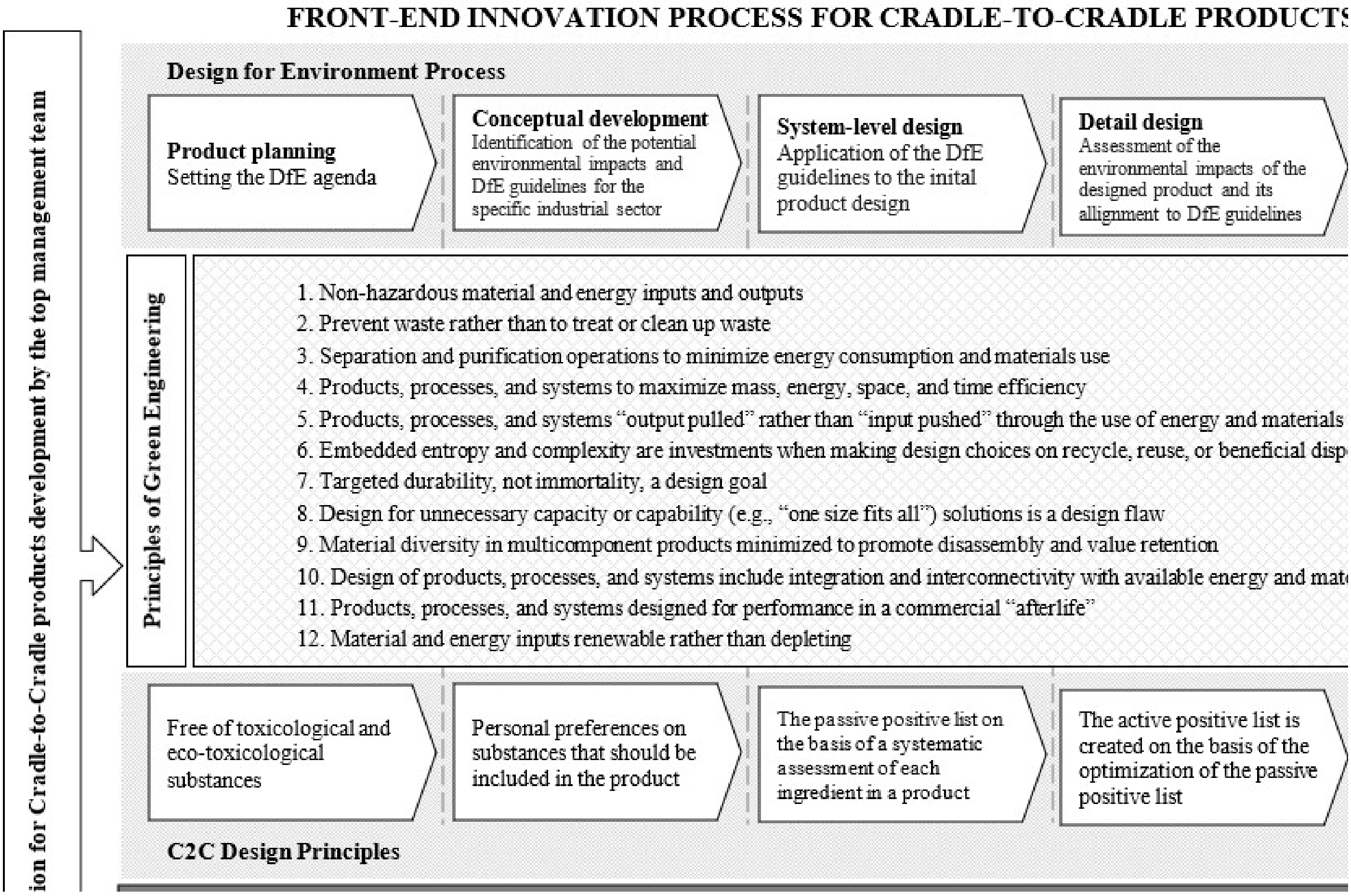

Figure 1. Management of C2C product development at the fuzzy front-end of the C2C innovation process (Based on Braungart, et al. 2007; Fahnenmüller et al., 2018; McDonough et al., 2003; Ulrich and Eppinger, 2011)

The framework indicates the criticality of the active management of a C2C product development team. Team composition should be based on cross-functionality which enables suitable conditions for transdisciplinary collaboration. There may even be multiple iterations of team re-composition along the innovation process as suggested by Fahnenmüller et al. (2018) to include people with necessary knowledge at each step of the C2C product design. The arrows in Figure 1 represent the openness of a team at certain points during the process for external knowledge or partnerships and thus new people to be included in the team depending on the upcoming task. This allows the team to get all the required perspectives from different disciplines when reinventing, exploring, and experimenting new team compositions as well as C2C product concepts and processes. Ideally, at the end of the fuzzy front-end C2C innovation phase, the team built in the iteration process is ready to test product concepts defined during this innovation phase and develop suitable cross-functional processes. The framework depicted in Figure 1 helps both academics and practitioners to understand the multiple aspects that need to be considered in a C2C innovation and development project. The framework can also help top management and managers of innovation teams to create long-term visions when planning the iterations in C2C solution development.

Conclusion

When setting up a C2C innovation process in a firm that does not have any experience with the challenges of implementing C2C earlier, the organization needs to first understand the special team requirements for designing and implementing complex C2C concepts and processes. The C2C design steps and the DfE process do not take into account the need to incorporate a wide range of stakeholders representing various disciplines and diverse backgrounds. The need for transdisciplinarity in C2C projects should be understood and considered by firms. This allows to build up teams that are more capable for innovating and implementing C2C projects. The new requirements for team set-ups also necessitate that teams are given more flexibility to break out from existing design processes. It is not only about the cross-functional teams or transdisciplinary knowledge, but about active management on the basis of transdisciplinary collaboration and constant re-thinking of the knowledge domains which should be present in the team in order to achieve the tasks at every stage of the C2C product innovation and development process. Top management in firms need to also understand better the fuzzy front-end C2C innovation process to aid in the selection of team members with diverse backgrounds and thus enable true transdisciplinarity in the C2C design teams. This is one of the preconditions for transitioning from a conventional innovation process to a C2C innovation process where re-invention could be the first step in the C2C design process.

Future Directions

The fuzzy front-end phase of the C2C innovation process requires unique transdisciplinary collaboration competences for widely exploring and experimenting novel product concepts to ensure that the C2C design is implemented according to the defined C2C design requirements. However, it has not been thoroughly researched how the front-end activities and the whole innovation process of C2C products differ from a general new product innovation process, or what specific skill sets, competences, and their combinations are required in C2C design teams. Future research could also explore how a transdisciplinary C2C design team can benefit from other entrepreneurial competences that enable the team members to understand how to take full advantage of the business opportunities for C2C innovations and build more successful business in the context of a circular economy.

Cross-References (*if applicable*)

Circular Economy; Sustainability-oriented innovation

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