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Document Version
Accepted author manuscript

Published in:
Resources, Conservation and Recycling

DOI:
10.1016/j.resconrec.2019.05.023

Publication date:
2019

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Journal article (Accepted manuscript*)

Please cite this article as:
Tate, W. L., Bals, L., Bals, C., & Foerstl, K. (2019). Seeing the Forest and not the Trees: Learning from Nature's Circular Economy. *Resources, Conservation and Recycling*, *149*, 115-129. https://doi.org/10.1016/j.resconrec.2019.05.023

DOI: https://doi.org/10.1016/j.resconrec.2019.05.023

Accepted at *Resources, Conservation & Recycling*, pre-publish version May 2019

Seeing the Forest and Not the Trees: Learning from Nature's Circular Economy

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Please cite as: Tate, W., Bals, L., Bals, C., and Foerstl, K. Forthcoming. Seeing the Forest and Not the Trees: Learning from Nature's Circular Economy, accepted at *Resources, Conservation & Recycling*.

Abstract

Managing for triple bottom line (TBL) by creating economic, ecological and social value is increasingly on the business agenda. However, it is challenging to address non-economic issues because businesses are designed to maximize profit and are less aligned with global ecological and social challenges. Shifting from linear supply chain thinking to interconnected, circular, ecosystem thinking could offer insights into addressing these challenges. Looking at time-tested patterns and strategies from natural ecosystems that operate using, reusing, and repurposing materials and components in a way that is sustainable, may allow for innovative and effective solutions for businesses to begin addressing these global challenges. Biomimicry, an approach to innovation that seeks solutions to human challenges by emulating nature, can inspire evolutionary and structural aspects of business ecosystems. Biomimetic insights related to mycorrhizal (root-fungus) networks are used as a foundation of this research. This research draws on network theory and complex adaptive systems (CAS) to translate the biomimetic language to the language of networked business systems. Based on literature and interview data gathered from five businesses, biomimetic principles were developed that can guide businesses as they transition from linear, wasteful chains to circular business value systems. In particular, business ecosystems require more participants in the roles of 'scavengers' and 'decomposers' and an underlying infrastructure, that helps to manage information and material flows in an integrated way.

Key Words: Biomimicry, Global Challenges, Networks, Complex Adaptive Systems, Mycorrhiza, Fungi

A struggle for businesses is how to better manage resources and create an economy which aims to eliminate waste altogether as is the case in natural ecosystems. Unlike most business processes, the natural environment is characterized by a continuous cycle of salvage and reuse, where waste from one process can become an input to another unrelated process (Stahel, 2016). Looking at the problem of e-waste, (Ryen et al. 2018) suggested that transition toward a circular economy industrial ecosystem needs to emulate natural systems to be effective.

A circular economy has been defined as one where resources and the value of materials are kept within the economy for as long as possible, and when a product has reached the end of its life, to be used again and again to create further value (EC, 2015). Waste and resource use are minimized. In the circular economy, waste from factories would become valuable inputs to other processes and even across industries as products are repaired, reused or upgraded or individual materials are repurposed instead of being thrown away (Preston, 2012). After analyzing a multitude of definitions of circular economy (CE), Kirchherr, Reike & Hekkert (2017) concluded that the circular economy is most frequently depicted as a combination of reduce, reuse and recycle activities. The problem with that perspective is that the circular economy is not positioned as a systemic shift, which is necessary to meet sustainability goals. The systemic perspective is central to this research, looking at the circular systems inherent in nature as a guide.

Companies are starting to realize the importance of looking to natural systems to better utilize existing resources and trying to emulate the more organic or fluid ecosystems (Winn & Pogutz, 2013). The lens they are looking through is referred to as biomimicry or biomimetics, a method imitating techniques and processes of nature to achieve effectiveness, efficiency and sustainability (Benyus, 1997). Biomimicry has been seen in new product development research and practice, such as, self-cleaning façade paints based on the water and dust-repellent properties of the lotus leaf (Sivakumar et al., 2012). However, biomimicry reaches beyond product development and includes management and organizational insights conceived from nature. Using biomimetic principles in innovation means that you are seeking sustainable solutions to human challenges by emulating nature's time-tested strategies. The goal is to create products, processes, and policies that are long lasting and resource efficient (Biomimicry Institute, 2017). Systemically incorporating biomimetic principles learned from nature into circular economic thinking, could transform the utilization of resources into a process that is more productive and far less wasteful then it is currently.

Natural ecosystems are viewed as complex adaptive systems (CAS) (Levin, 1998), the theoretical lens used to ground this research. An industrial ecosystem perspective builds on the tenets of a natural ecosystem in that all waste materials have potential nutritional value, and industrial activities are approached with the goal of overall efficiency optimization to achieve complete waste elimination (Bakshi & Fiksel, 2003). Industrial ecology researchers believe that networks of industries can be designed in analogy to food webs to reach a sustainable and efficient state (e.g. Frosch, 1992; Frosch & Gallopoulos, 1989). That said, while the available tools for systematic design of industrial ecology networks have been developing (Allen & Butner, 2002), research to derive robust biomimetic design principles is still being conducted (Layton, Bras & Weissburg, 2015). Some biomimetic principles seen in the literature include the idea of 'roundput' or 'closed-loops' (Korhonen, 2001a, b), 'diversity' of actors (especially producers, consumers, decomposers), 'interdependency' and 'cooperation' (Geng & Côté, 2002; Graedel and Allenby, 1995; Husar, 1994; Tibbs, 1992; Jelinski et al., 1992; Frosch and Gallopoulos, 1989).

Having an in-depth look at the actor role of 'decomposer' in forest ecosystems, those that decompose organic materials and reduce them to simpler forms, this research aims to integrate the concepts of systems and network thinking with biomimicry for business ecosystem design. Current business ecosystems are largely dominated by producers and consumers, which would be the trees and animals in a forest ecosystem. The research looks specifically at the biomimetic possibilities in networks of mycorrhizal (the term for "root-fungus") fungi. Within the natural ecosystems, the mycorrhizal networks play a central role in carbon, water and nutrient cycling and redistribution of resources and information among trees (Allen, 2007; Eason et al., 1991; Simard et al., 1997; Treseder, 2004; Warren et al., 2008), which is needed to keep the forest systems circular and self-sustaining. These fungi have been studied in biology for decades (Simard et al., 2012) but not in relationship to business ecosystems.

Industrial ecology research has noted that actors involved in cultural systems or business contexts, may have conflicting interests. The way of mobilizing material and energy flows brings up issues of system structure and organization (Korhonen and Snäkin, 2005). This research goes beyond the usual industrial ecology research focus on material and energy flows (Korhonen and Snäkin, 2005), and delves into the fungi context which provides an integrated perspective of how material and information flows are managed simultaneously, essential for the forest ecosystem's circularity. This perspective was then discussed in interviews with five firms to better understand the application of this circular thinking in a business context.

The underlying rationale in this research is that in order to have business ecosystems become circular, we have to look beyond the producers (i.e. the trees), and instead see the systemic side of the forest ecosystems, which heavily draw on the underlying mycorrhiza network, resembling the decomposer role and managing information and material flows. Hence the title of this paper. The specific research question in focus here is: *"How can biomimetic principles be utilized to transition from a mechanistic linear business ecosystem to a circular value system?"*

To answer this question, a review of literature on the processes and operations of a mycorrhizal network in forests was performed and then established concepts from network theory and CAS were analyzed.

The concepts discovered from this assessment allowed for the design of an in-depth case study with an innovative focal organization, FBBasic, that recognizes the importance of circular systems. FBBasic has developed specific solutions for business networks to promote and enhance circularity. Within an industrial ecosystem, FBBasic acts in the 'decomposer' role, enabling circularity by providing a decentralized circuit for the required management of information flows, as a precondition for circular material flows. In addition, four companies that play the role of 'producer' within this ecosystem were also interviewed. Each of these producers is striving to make their products easier to decompose and these interviewees helped to shed light on the interrelationship between producers and decomposers. Based on reflection and elaboration of the case study findings in relation to the biomimetic setting of mycorrhizal networks, six biomimetic principles developed that pave the way to future research. Before concluding the paper, contributions to management theory, practice and education as well as future research suggestions are discussed.

COMPLEX ADAPTIVE SYSTEMS (CAS) AND NETWORKS: NATURAL VERSUS BUSINESS CONTEXTS

The basic assumption in complex adaptive system (CAS) research is that actors do not exist in isolation, but are part of a network or a system that emerges over time into a coherent form, adapting and organizing itself without a singular entity controlling or managing it deliberately, and should not be treated as independent, isolated entities (Holland, 1995; Dooley and Van de Ven, 1999; Choi et al., 2001). Forests are prime examples of complex systems (Filotas et al., 2014; Perry, 1994), exhibiting properties of heterogeneity, hierarchy, self-organization, openness, adaptation, memory, non-linearity, and uncertainty (Boccara 2004; Filotas et al., 2014; Mitchell, 2009; Solé & Goodwin, 2000). The adaptation of the overall ecosystem stems from the interacting of the organisms, and evolving in response to system changes (for example climate change), further influencing self-organization (Levin, 2005). This adaptive, self-organization is fundamental to the complexity and stability of these forests (Suding et al., 2004).

CAS theory focuses on the relationships of *actors* in the network, the network structure, as well as the degree of embeddedness and types of these relationships, in addition to the attributes of the actors (Dooley, 1997; Lichtenstein, et al., 2006). Within CAS it is assumed that patterned relationships among multiple actors affect their behaviors, attitudes and cognitions. Network theory has also been used in research on mycorrhizal networks. It has been suggested that the removal of the hub, or older trees, would over-proportionally decrease the resilience and resource transfer capacity of the network (Beiler et al., 2010).

In mature natural ecosystems, circularity of resource usage is ensured as members of the system occupy one or multiple of four roles: producers, consumers, scavengers and decomposers (Geng & Côté, 2002; Liwarska-Bizukojc et al., 2009), also sometimes termed predators, prey, decomposers and foragers (Ryen et al., 2018). In natural ecosystems, exemplary primary producers are plants that capture energy and supply food; consumers process the food and energy generated by the producers. Scavengers are animals that search and feed on dead plants and carcasses and prepare for the decomposers such as cockroaches, raccoons, jackals and hyenas (Geng & Côté, 2002). Decomposers, the bacteria and fungi that break down material for recycling, (Côté, 2000; Seigler, 2018) then help facilitate the circularity of the process. The health of the ecosystem is dependent upon the balance of production of the producers to make enough food for the consumers, which in turn must not deplete resources (Rogers, 2017; Geng & Côté, 2002).

The industrial system has important similarities to natural ecosystems as both systems take in energy and materials and transform them into products (Allenby & Cooper, 1994). However, current industrial systems operate in a linear 'take, make and waste' rather than a cyclical fashion (Babbitt et al., 2018; Geng & Côté, 2002; Preston, 2012). Being cyclical makes natural systems more efficient in their use of materials (Côté, 2000). In general, the idea is that materials and energy make their way from producers through different levels of consumers before finally being returned to the system by scavengers and decomposers (Geng & Côté, 2002).

In the business ecosystem, primary producers would be represented by extractors (e.g. mining companies) that drill and harvest from the Earth's surface to provide raw materials for other industries (Marshall, et al., 2014). Those industries that use the raw materials from the producers to create secondary raw materials are known as secondary producers, in most cases the manufacturing companies refining the raw materials and processing them into finished materials and products (Fisher, 1939). Primary consumers are businesses such as wholesalers, and secondary consumers are retail businesses, while tertiary consumers would include companies and customers that directly consume the output of the former two (Geng & Côté, 2002). In mature natural ecosystems the producers, scavengers and decomposers are the majority, the consumers the minority. That relationship is inverted in the current industrial ecosystem (Geng & Côté, 2002). In the industrial ecosystem, there are fewer primary producers (resources are limited) and the number of consumers (i.e. consumption of resources) is high. In both systems, balance between producers and consumers is important to ensure availability of resources (Dhungana et al., 2010).

Scavengers are those companies that feed off the waste resources of other companies in the system, redistributing resources (e.g. dismantling, sorting and transporting the materials to decomposers) (Asim, et al., 2012) back into the system to companies that can reuse the materials. They facilitate the role of those companies that recycle materials by transporting the materials in a form that is readily accessible for them to process (Geng & Côté, 2002). Decomposers are those companies that use waste resources from the producers, consumers and scavengers, who "transform or recycle them back into the system as new materials or as part of the same materials for which they were initially designed" (Geng & Côté, 2002: 336). One example is a composting facility. Scavengers and decomposers play an important role in the creation of circular industrial ecosystems (Besiou, et al., 2012; Ryen et al., 2018). In the natural ecosystem scavengers and decomposers ensure that resources continue to be available for reuse in the ecosystem, the business ecosystem requires these roles to ensure continued sustainability and availability of resources (Geng & Côté, 2002). Table 1 summarizes the comparison.

Please insert Table 1 about here

Structural characteristics of the network are generally based on linear thinking and referred to as horizontal, vertical, and spatial complexity (Choi et al., 2001; Choi & Hong, 2002; Choi & Krause, 2006). These characteristics are affected by the number of actors and relationships (horizontal complexity), the number of tiers (vertical complexity), and the physical distance between (in-)direct buyers and customers (spatial complexity) (Choi & Hong, 2002). Networks have been characterized along additional dimensions such as centrality, network centralization, network density, reciprocity, and interdependence (Bellamy et al., 2014; Gulati & Gargiulo, 1999; Kim et al., 2011; Wilhelm et al., 2016). Moreover, the role of information and product brokers creating efficiency, interaction and adaptation in such complex networks has been highlighted (Saunders et al., 2017).

The network view and CAS is extended to *circular systems* using a biomimetic perspective, recognizing that each living thing has structure and organization, and single parts and processes cannot provide a complete explanation of the phenomena (von Bertalanffy, 1934). If the goal is to create a circular economy, then the aim should be to facilitate the emergence of a self-organizing system with the desired characteristics.

To better understand how natural systems might inform business systems and how natural ecosystems maintain information transparency as well as coordination of material flows in the biomimicry setting, a mycorrhizal network within a forest provides a context for assessment. Playing a decomposer role, the mycorrhizal networks gather nutrients and trade them with plants (in exchange for sugar), so that the plants do not have to develop extensive root networks (Rade, 2015). The fungi provide the infrastructure for a lively two-way exchange of nutrients and information between different species of trees, and they link the roots of multiple species of plants, facilitating transfer of carbon, nutrients or water between the plants (Simard, 2009). Thereby, their role as decomposers and their coordination of material and information flows is central to the forest ecosystem's circularity.

The mycorrhizal networks can mediate the way in which resources among trees or plants are distributed, as they link the trees in space and time, transferring nutrients, water and carbon between older and younger trees according to their needs (Simard, 2009). In the network and extended enterprise literature the fungal network would be considered an overlooking rational coordinator (or broker) of the entire tree network (Saunders et al., 2017). While this broker is selfseeking, it neither behaves opportunistically toward network members, nor does it act partially toward specific members of the complex adaptive system (Kalish, 2008).

In terms of the *systems* versus *network* terminology, the usage of the terms in the context of forests is that mycorrhizal *networks* play a central role in the functioning of ecosystems as *complex adaptive systems* (Levin, 2005). In fact, with the help of this network, a complex underground trading system is established within a 'highly integrated community', that also helps to structure and stabilize ecosystems (Simard, 2009: 101). The mycorrhizal network integrates multiple plant and fungal species that interact, provide feedback and adapt, and resemble a complex adaptive social network Gorzelak et al. (2015). While forest ecosystems are complex adaptive *systems*, its sub-element that is in focus for this research is the mycorrhizal *network*. Table 2 compares and contrasts the ecosystem of the natural environment to that of the business environment, summarizing constructs from systems theory (Kast and Rosenzweig, 1972; von Bertalanffy, 1934, 1972) . What this highlights, is that there are many differences between natural ecosystems and business ecosystems. For example, while natural ecosystems are characterized by a balance of all four actor types, business ecosystems are dominated by producers and consumers, but lack scavengers and decomposers.

Please insert Table 2 about here

Looking at how such ecosystems are usually visualized in biology and business research, Figure 1 provides an illustration. On the left, are two depictions from forest ecosystem-related research and on the right, there is a business ecosystem depiction. The differences highlighted in Table 2, show that producers and consumers prevail in business ecosystems and that their networks are sparse compared to that of the highly dense fungi networks in forest ecosystems.

Please insert Figure 1 about here

Therefore, the review of the fungi network-related literature and this comparison of natural and business ecosystem characteristics suggests that the role of mycorrhizal fungi as a decomposer *actor* as well as their effect on network *structure* are central constructs for forest ecosystem circularity. The question is whether the constructs of the decomposer actor and network structure can be transferred to a business context. Biomimicry provides the lens to view the phenomenon and the next section introduces our empirical analysis in the business context.

CASE STUDY METHOD

Rationale and Sampling

Following the primary research question, *how can biomimetic principles be utilized to transition from the current mechanistic linear business ecosystem to a circular value system,* the goal was to explore the focal constructs of *actors* and *structure* in the empirical context of business ecosystems. In particular, a qualitative, inductive research design was applied (Eisenhardt, 1989; Yin, 2009). This approach allowed for the identification and exploration of the relevant constructs and interrelationships, adding description and understanding of the interactions, meanings, and processes that constitute real-life settings (Gephart, 2004).

Based on the analysis of the role of mycorrhizal fungi in forest ecosystems and the clarification that their effect on structure as integrators of information and material flows is key to circularity in the natural context, an extreme sampling logic was followed to select the focal case, FBBasic, in the business context. This enabled research into a company that operates at the forefront of creating circular value systems for different products and industries, also tackling both the material and information flow aspects. FBBasic is an umbrella company that supports the circular infrastructure of other organizations, essentially acting in a 'decomposer' role.

An overview and clearer understanding of FBBasic and its role within circular value systems is detailed in the case analysis section. This particular case was chosen for its potential to illuminate and extend relationships and logic among constructs, that is, for their potential contribution to theory elaboration and development (Eisenhardt & Graebner, 2007; Vaughan, 1992). In addition, four producing companies – Tarkett, Interface, EmmaShoes and Havep were selected as businesses that proactively work to make their products more "decomposable", representing the 'producers' in the business ecosystem, in analogy to the trees in the forest ecosystem.

Data Collection and Selection of Informants

The case study approach enabled the use of multiple methods of data collection for an in-depth exploration of the phenomena within their natural setting (Yin, 2009). A semi-structured interview protocol (see Appendix A) was developed with open-ended questions to enable interviewees to describe events and processes, to facilitate comparability of findings, and to retain the flexibility to probe deeper into emergent themes by eliciting examples, illustrations, and other insights. Data collection comprised of multiple in-depth interviews, publicly available interviews, a transcript of a seminar held by FBBasic and other documents that were obtained throughout the interview process with five companies: FBBasic, Tarkett (formerly Desso), Interface, Emma Safety Footwear and Havep. In total, there were six interviewees, but the interviewee from

FBBasic was interviewed three times in order to cover the entire interview guide as there was a lot of detail to be shared. All participants gave their informed consent to participate in this study.

The latter were nominated by FBBasic to add the producer perspective. This helped the researchers to gain an understanding of the phenomena from the view of those studied and to examine and articulate processes (Pratt, 2009), including the meanings ascribed by informants to actions and settings (Gephart, 2004). The interviews each lasted 60 to 90 minutes (Glaser & Strauss, 1967). Other secondary data was collected in the form of publicly available documents (e.g., annual reports, firm systems data), publicly available short videos (e.g., a brief documentary by the Ellen MacArthur Foundation on the circular economy, featuring Tarkett) and internal firm documents (e.g., company presentations, process documentation, an overview of partners and collaborating institutions, organizational charts).

The Decomposer - FBBasic

FBBasic focuses primarily on the recovery of raw materials. Driven by the increasing scarcity of, and limited access to specific raw materials, FBBasic's mission follows the idea that no resources should be lost. This is achieved by switching to a model of "active" recycling, where the "next use" for materials is already defined at the design phase – whether it is within the same product category, or potentially cross-industry. FBBasic leverages IT applications to connect the complex system of producers, storage firms, transportation organizations, financial firms, policy makers and others that are involved in the quest for zero waste and cradle to cradle thinking. They help companies, governments, and other institutions convert their linear production into a circular concept by developing, guiding, operationalizing and delivering corresponding IT applications. FBBasic relies on its large network of specialists to manage the material passport as items move within and across industry. A material passport contains all of the materials included in a product or construction. By defining the characteristics of the materials, it gives them value for recovery, recycling and reuse.

FBBasic follows the belief that there will be a real paradigm shift in business thinking. According to the founder of FBBasic, there is no way for a planet and economy to survive with a "take, make, use and throw away" approach. Circular value networks are a new way to look at the world, the economy and organizations. At the same time, changes in technology such as developments in the internet of things, artificial intelligence and blockchain, are revolutionizing the way that companies can, and some are, doing business. Blockchain technology, for example, offers the chance to store immutable information ubiquitously and decentrally (Swan, 2015), features that could foster sustainable supply chains (Saberi, Kouhizadeh & Sarkis, 2018). FBBasic is leveraging this technology for its material passport. The founder describes the different business areas as follows, covering organizational/logistics consulting, reverse logistics and a material databank/passport:

> *"I support and help customers in developing circular products and supporting systems and I'm not talking [only] about IT-Systems, but let's say logistics or organizational systems. […] We have a little company that develops and exploits applications supporting the circular economy. One could think of a very classical waste to resource application for those companies who are still in the phase from waste to resource but also, we have the material passport –the digital material passport. We have a material bank for secondary raw materials and we are now developing a market place for secondary raw materials and we are developing a platform to connect the sustainable development goals to really concrete practical dashboards surrounding circular systems and solutions. […] FBBasic on one hand is the parent-company of all my activities and on the other hand let's say it's the advisory branch."* (FBBasic)

The producers – Tarkett, Interface, Emma Safety Footwear and Havep

At Tarkett (formerly Desso), one of the largest flooring manufacturers in the world and a frontrunner of the cradle-to-cradle concept (McDonough & Braungart, 2010; Braungart et al., 2007; Braungart and McDonough, 2002), the primary belief is that precious resources must be retained in order to exploit the potential economic value within them. Products have to be intelligently designed for disassembly and reuse in order to recover the valuable materials and turn them into resources at the end of their usage lifecycle Their belief is that “creativity could eventually lead to endless reuse of scarce resources while improving people’s well-being and health”.

At Interface, the motto is “’comply’ is not a vision” (Interface, 2013) and the global carpet manufacturer and producer of other floor-covering products for commercial, institutional and residential markets has been striving to incorporate sustainability into its products deliberately for about two decades, with the aim to become a restorative company by 2020 (The natural step, 2013), bringing recycled and bio-based products to a 100 percent.

At Emma Safety Footwear, currently the first six models are available and by the end of 2019, the whole collection needs to be made in a circular way. The business has its origin in being established as a social company by the Dutch State Mines (DSM) to produce safety shoes for miners (Emma Safety Footwear, 2019). Today, they are highly committed to design circularity into their products – material health and recuperation of materials are some of the main design aspects. They are currently working on arranging a circular system, including reverse logistics, next used application and material passport.

At Havep, a producer of both off-the-shelf and customized protective wear and workwear, engagement in the fair wear foundation started in 2004 and in 2012 it launched its circular Havep Rework collection. Havep is a family-owned business, which has been in business more than 150 years. Their sustainable ambition for 2025 is to get to 90% circularity for their products (Havep, 2019).

Data Analysis and Coding

All interviews and a number of videos were transcribed as a basis for coding analysis according to Strauss and Corbin (1998). This procedure also facilitated the recording of notes, memos, ideas, and comments. The coding was done in the qualitative data analysis software NVivo 11 with a pre-defined coding tree (Bazeley & Jackson, 2013) based on the constructs shown in Table 2 related to actors and structural characteristics. Additional open coding was added during the analysis (e.g. "reverse logistics"). A coding log was kept to ensure a transparent and traceable qualitative data analysis approach.

To ensure and increase the inter-coder reliability in NVivo 11, at the start of the coding a joint review of one commonly coded transcript was conducted by two coders. This also ensured consistency of the use of individual nodes in the coding process, for example through showing that an individual had coded part of a quote under the actor role 'decomposer', while another under 'scavenger'. Such discrepancies were then discussed to resolve the underlying variation in understanding for the continuation of coding all of the transcripts by the two researchers. This helped to ensure a transparent and traceable qualitative data analysis approach (Bazeley, 2013). The results then served to derive the biomimetic principles discussed in the following sections by using axial and selective coding procedures (Strauss & Corbin, 1998).

CASE STUDY RESULTS: PRINCIPLES FOR TRANSITIONING TO CIRCULAR VALUE SYSTEMS

The analysis performed in this research led to the formulation of six biomimetic principles for circular value systems. Table 3 illustrates the relationships between the constructs derived from network and CAS literature, a brief summary of the empirical evidence and the principles. Table 4 provides additional cross-case illustrations for each principle. Figure 4 highlights how these principles foster a new way of seeing in comparison to the current status quo of business ecosystems – related to both the role of actors/agents and the structural characteristics. As shown in Figure 4, particularly the underlying information base in form of the material passport and the reverse logistics for the material flow – in forest ecosystems provided by the mycorrhizal network, in the business context resembled by FBBasic – are essential to establish resource circularity. The right side in Figure 4 (the proposed view of circular business ecosystems) has a much closer resemblance to the forest ecosystem depictions that were shown in Figure 1 on the left side (the mapping of forest ecosystem relationships from biology research) than the depictions of current business ecosystems in both Figures 1 and 4. Each of the principles is discussed next.

Please insert Tables 3 + 4 about here

Please insert Figure 4 about here

Insights on the Roles of Agents/Actors

Three of the developed principles focus on the role of the agents and actors. In both the literature and the interviews, it was apparent that there were significant difference between the actors in the business versus the natural ecosystem. The role that FBBasic plays in these networks is crucial to bring circularity into the business ecosystem.

Principle 1: In order to transition to a circular value system, the ecosystem needs an appropriate balance of actors

Upon first glance, this may seem obvious. However, comparing the natural ecosystem to a business ecosystem there is an imbalance of actors on the business side leading to over-consumption and excess waste. Healthy natural ecosystems have a balance of all four actor roles – producers, consumers, scavengers and decomposers. After analyzing the case data, the first biomimetic principle required to move from the current ecosystem view to a circular value system is to increase the number of scavengers and decomposers, which are limited in the existing business environment. FBBasic acts as a decomposer in the business ecosystem and describes the need for more reverse logistics and materials recuperation (in natural ecosystem terms: scavengers and decomposers) in the ecosystem, the need for system integrators was highlighted:

> *"[…] to make a viable picture or business model you have to […] create mass and that means that there will be new system integrators. So, it can be present system integrators that recognized a new role and will evolve into this new role, but also could mean that there will be […] changing business models. […] And the original added value that they are able to assemble [….] a package for the customers let's say around safety shoes, work wear and helmets and things like that. And that's their reason of being in this world. Some of them, they recognize that they can be the new system integrators in the circularity approach. And they can offer track and trace of products for the customers. The products… can be taken back and they keep their value." (FBBasic)*

Principle 2: In order to transition to a circular value system, information and material flows must be managed in an integrated way

The tracking of information and material flows is crucial in a circular ecosystem. Consider for example content laws and regulations. Producers must be able to confirm a given percent of recycled material, or even chemical makeup in that material. As items transform in a circular society, the material passport is critical. While transparency on resources centers on the information flows within the business ecosystem, the theme of material recovery relates to the actual material flows. While the mycorrhizal network provides both material and information flows, at the same time, in forest ecosystems, our current business ecosystem does not have such an established infrastructure to manage both flows. In contrast, the situation underlines the current linearity of material flows from production, to consumption, to waste in single lifecycles. At

Tarkett, what is described is that the reverse processes have basically been internalized by the company itself.

They indicated that companies will need to change their current mindset in order to develop the necessary infrastructure to process secondary materials. For some companies, this change in mindset might be driven by disruptions in their existing material flows, due to shortages, conflicts and other reasons. While for others, with increased information transparency, it will become easier to identify the value in building the infrastructure to get materials back. Until a shared mindset and set of standards is established, forerunners like FBBasic, Tarkett, Interface, Emma Safety Footwear and Havep have to rely on building their own infrastructure.

Principle 3: In order to transition to a circular value system, producers should have their outputs designed for reversed material flows

The reverse logistics' efficiency stands and falls with the product design, i.e. whether a product by design lends itself to efficient, safe and quality-retaining disassembly. Unfortunately, there is no common standard to measure ease of disassembly (Vanegas et al., 2018). Also, there are other issues that make recycling and disassembly challenging. For example, in the case of metals, closing material loops is particularly difficult as long as prices for virgin materials are lower than the costs of recycling (Jacobi, Haas, Wiedenhofer & Mayer, 2018). Therefore, it is critical that product design by manufacturers should lend itself to easy decomposition, remanufacturing and upgrading (Haas et al., 2015; Stahel, 2016). In the language of the natural ecosystems, it is how "easily digestible" the product is for how many of the consumers, scavengers and decomposers. This view on products from a business perspective insinuates that there is only a temporary accumulation of certain materials/resources together

"[…] we don´t envisage products from a waste perspective. […]. A product is not more than a composition of raw materials in a certain stage. That´s very abstract, how we tell it. But that´s also psychological. […] for example, one would say the waste management companies have the best reverse logistics systems in the world. Why not use their networks? I tried. But, as long as they envisage this as a waste product then it will not have the value that it should have and it will [not receive] the care it needs." (FBBasic)

Another aspect of this change in mindset is to not assume that "waste", or rather recuperated materials, is of worse quality than primary/virgin materials. Instead, the new way of seeing should incorporate the quality characteristics of secondary materials into the product design and production. Like with primary materials, for which different sites/mines produce different qualities, secondary material qualities also need to be analyzed and considered. In this context, it would make sense to think of the sources for secondary materials as "urban mines" of different quality grades. This thought is reflected below.

"People think a quality will degrade over time. Of course, that's a fact but in the primary raw material business it's the same. […] let´s say the iron ore from a certain pit in Australia has another quality than the iron ore in a pit in China or in the US. And all these grades have been defined and recipes have been defined on that as well. The same should take place in the recuperation of raw materials. And people always think, 'okay, then a recuperated has to be the same quality as the original. Otherwise it doesn't work.' And then I say 'well, please look at the primary raw material business. Also, there you have various grades and there you have to make recipes for that.'" (FBBasic)

Insights on the Structural Characteristics

The other key differences between the forest and business ecosystems relate to the structure of the ecosystem. These flows are not linear, and often times have to cross over industry (and product) boundaries to continue in the lifecycle.

Principle 4: In order to transition to a circular value system, secondary material flows need to continuously cross industry boundaries

In contrast to linear thinking in specific industries' supply chains, FBBasic's multi-lifecycle perspective considers that the future uses might include completely different industries, truly moving within a circular value system instead of in a linear supply chain ending at a landfill. This process has many similarities to the mycorrhizal network, spanning multi-species (Simard, 2009). This multi-lifecycle perspective is illustrated.

Advances in technology help in the coordination of material and information flows related to recovered materials. The logistics to identify and move the recovered materials to a place where they can be best utilized must be transparent, efficient and affordable. For this purpose, the founder of FBBasic believes in the materials passport and a materials bank dedicated to secondary raw materials. By being the facilitator of this movement and the keeper of the material information, in the form of the material passport and the material bank, FBBasic is working to push the disposable society to a circular value system.

Below is a look into this new type of system, as it relates to the movement of resources from one use to the next and across different products. The figure below illustrates the idea of connecting value circles from the perspective of FBBasic. FBBasic provides information, storage and movement of materials. They act as a 'broker' to other firms in the circular value system.

Please insert Figure 2 about here

The mycorrhizal networks "are fundamental agents of complex adaptive systems (ecosystems) because they provide avenues for feedback and cross-scale interactions that lead to self-organization and emergent properties in ecosystems" (Simard et al., 2012: 39). In a similar way, FBBasic acts as a fundamental agent of an emergent complex adaptive system of businesses exchanging their resources. FBBasic acts similarly to the fungi in the forest network. The figure below illustrates that similarity, as it shows how like a mycorrhizal root network, FBBasic's materials databank provides a connection between otherwise separate companies (like the trees in the depiction on the left) or even industries (as shown above in Figure 2, even moving across diverse industry boundaries such as automotive, textiles and chemicals, in analogy to the inter-species connections of the mycorrhizal fungi network).

Please insert Figure 3 about here

Principle 5: In order to transition to a circular value system, network density between heterogeneous members is needed.

Like in a natural ecosystem with a plethora of different, partly overlapping niches, the case analysis highlighted the need to find partners with complementary capabilities and work jointly to solve issues, such as breaking down a complex product back into its original materials. In natural ecosystems, a greater number of very specialized system members leads to more interconnections, meaning a higher density, which again buffers against external shocks and thus increases resiliency. Increases in specialization can be argued to lead to more efficient resource allocation. In this sense "natural systems are divided into niches, with cooperation among differentiated entities, which is more efficient than competition; in ecosystems, for example, each species fulfills a specific role" (Rade, 2015). The mycorrhizal network provides an infrastructure for such a 'super-cooperator' versus 'super-competitor' system (Simard, 2016).

The move to a circular value system needs collaboration within the network to achieve mutual benefit and bridge to other network members. This should occur when there is an opportunity to leverage the respective capabilities. The following is an illustration.

> *"We have a philosophy that everybody is responsible for his own P&L and for his or her own results and we don't earn from each other, but we earn together, we develop new businesses together. For example, one of my partners in the network: he is really an expert in the real estate market, has created a successful management dashboard for real estate, especially for social housing. We are able, through our material passport, to add circularity to the social housing*

sector. We make these kinds of connections. That´s also the way we were connected to blockchain. I was asked for my logistics background, if I would like to join a blockchain project with the technical university of Delft […] I said okay, if we can add the aspects of circularity in it and then I´m your guy. And so, in this way we expand to connect new businesses." (FBBasic)

Principle 6: In order to transition to a circular value system, the ecosystem needs reliable, decentralized information storage.

The shift to the circular business ecosystem requires decentralized information storage solution in the form of a material passport and the secondary material bank, in analogy to a mycorrhizal network. Similar findings were also shared by Baldé et al. (2017: 5), who found that it is unclear what happens to about 76% (34.1 Mt) of e-waste, and state that it likely is traded, dumped, or recycled under worse conditions. This highlights the critical role of decentralized information storage in order to provide transparency at all times and places. One important stepping stone in achieving this is reaching common agreement on driving information sharing and reporting standards. Unfortunately, current information flows are still highly fragmented or non-existent. For example, Baldé et al. (2017) highlight that only 41 countries currently have e-waste statistics and it is not possible to track e-waste flowing from richer to poorer countries. This is a hindrance to optimal 'foraging' of these e-waste resources, as for example proposed in analogy to nature by Ryen et al. (2018).

The information flows enable the (long-term) material flow optimization. This includes optimized routing, but also establishing closed-loop systems, in which waste from one process is input for another process. A key pre-requisite is the ability to store information on materials through "geography and time" (as the interviewee from Tarkett put it; Table 4), covering aspects of materials characteristics, origin, ownership use, value etc.

"And that's also why we say to our customers, so the manufacturers, we say 'please, identify your products. It helps you in the total supply cycle'. For example, for work wear or safety shoes […] you know in the end what distributor, what customer, what company, but also what wearer is connected to this shoe or the piece of clothing. And I need it when it gets back that we can easier identify the

> *material. And now we do it by looking at it. By putting a QR code for example […] in front of a reader. But if we can do that by a chip that really enables our processes."* (FBBasic)

Regarding how FBBasic intends to connect the firms and let them exchange resources, essentially becoming the nexus of information within the ecosystem to create resource transparency. (The "C" in front of some of the terms stands for "circular"):

> *"That parties will find each other by themselves [via the material database]. The next application that we still have to build is what we call C-Market [...] Then we have the C-Bank, a C-market supported by the C-Passport. That are the developments we are working on now [plus] C-dashboards, something completely different."*

DISCUSSION: IMPLICATIONS TO SUSTAINABILITY RESEARCH AND PRACTICE

The six principles derived from the analyses have both managerial and theoretical implications. These are now discussed.

Implications for Research

If the premise of the network or CAS under analysis is to deliver sustainable performance (in economic, environmental and social terms), this research proposes an elaboration to the existing variables in business research. It suggests a need to incorporate ecosystem concepts into a business context, moving beyond analyzing ecosystem producers and consumers, deliberately including the two roles of scavengers and decomposers.

This research also suggests that it is important to move beyond the focus of linear flows of either materials and/or information and/or financial flows, to a perspective that considers these flows simultaneously. Also, reverse flows should be deliberately planned for in materials and the topic of product design should be a corner stone to ease or hinder this flow. Like the discussion around supply cycles crossing industry boundaries, the flow of materials beyond industry boundaries also warrants future research when it comes to circularity. The highlighted reliance on a dense network of partners suggests to study ecosystem members with a synergistic lens, looking beyond traditional large firm actors, to deliberately include start-ups, intrinsically motivated individuals or NGOs are also other opportunities for future research. The decentralization of information by new means such as blockchain technology challenges assumptions of centrality, suggesting further reflection on the latest technological developments in terms of decentralized information storage and processing.

In relation to recent research on how a multi-agent architecture for the circular economy could look like based on industrial metabolism considerations (Gómez et al., 2018), this research particularly highlights the roles of the decomposer agent (FBBasic), the design and production agent (Tarkett, Interface, Emma Safety Footwear and Havep) and importance of a common knowledge base and ontology (material passport). Generalizing beyond the particular companies looked at here, this research highlights how material and information flows need to become more integrated and whom and what it will take to do so (e.g. more decomposers).

Implications for Practice

The proposed six principles offer a new way of seeing to practice, too, in that they provide some inspiration to transition toward a circular value system. A first implication is to integrate scavenger and/or decomposer related processes into one's own business. Tarkett illustrated that, although being a producer, they have branched out into the scavenging and decomposing to fill the void they recognized. After a more stable infrastructure that includes specialized scavengers and decomposers evolves, partnering might become an easier strategy for companies not having the financial resources and/or expertise to branch out.

A second implication is that the integrated management of information and material flows requires technical solutions that are capable of facilitating such an approach. FBBasic illustrated such a solution based on blockchain technology, simultaneously illustrating that a broker like that might be a quicker solution for companies than trying to build up such solutions themselves. Following the idea of allocating resources continuously and seamlessly where they are needed within the business ecosystem, cross-industry standards are key.

A third implication is to design products for easy disassembly and with multiple-lifecycles in mind, deliberately including reverse flows for materials into supply chain planning. Those going first with such design might benefit once material scarcity truly materializes, being the ones who are able to produce amidst scarcity, potentially gaining market share. Like Interface illustrated, amassing the required volumes for efficient recycling might need some creativity (e.g. identifying that fishnets have the same nylon like flooring products), but once implemented, provide a reliable stream of production materials. Also, potentially organize new product development and other organizational processes along modular products with high reliance on specialized partners in the ecosystem that can amass economies of scale over various networks. When identifying intrinsically motivated suppliers, empower them to co-evolve. Companies can become supporters and advocates of transparency and information collection across all stages of production, consumption as well as multiple product life cycles, cooperating toward a common standard (e.g. ubiquitous material passport).

CONCLUSIONS, LIMITATIONS AND SUGGESTIONS FOR FUTURE RESEARCH

This research set out with the purpose to better understanding the shift of perspective from a closed, mechanistic business ecosystem, to a circular value system. The specific research question posed was "*How can biomimetic principles be utilized to transition from the current linear mechanistic business ecosystem to a circular value system?"*

The research addressed this question by reviewing literature from the field of biology on forest ecosystems, particularly the mycorrhizal fungi network, reviewing the main variables of network theory and CAS, and conducting case study research. From the analysis, six biomimetic principles were derived. In terms of what this implies for a circular economy, Kirchherr et al. (2017) stated that "[circular economy] affects the design, production, use and disposal process, and the collection of products and materials for reuse. It also adds new processes to facilitate, maintain, share, repair, upgrade and remanufacture products" (van Buren, Demmers, van der Heijden & Witlox, 2016:3). With a systematic perspective, the biomimetic principles proposed in this research resemble the breadth of these aspects.

The case study research in this paper relies on interviews and materials related to five organizations. For future research, widening the scope of companies and also following a longitudinal approach holds further potential. Nevertheless, FBBasic together with Tarkett, Interface, EmmaShoes and Havep provided a unique opportunity to study an early emergence of a mycorrhizal-like network element toward a circular economy. Although this resembles a limited empirical base for this paper, it illustrates the integration of material and information flows noted in the mycorrhizal networks in the business context.

Another aspect for further consideration is that mycorrhizal networks combine information and material flows within one ubiquitous network, combining both the transfer of information and nutrients (Simard et al., 2012). An upcoming area of business research that could therefore strongly benefit from a biomimetic perspective is the area of ‘physical internet’, combining the information and physical material flows in an internet-like hub and spoke system (Sternberg & Norrman, 2017). The mycorrhizal networks, as a result of natures tried and tested evolution, might also be of avail to design those. Here, the linkage to existing research concerning industrial symbiosis (Domenech et al., 2019; Ashton, 2008) and industrial metabolism (Gómez, González & Bárcena, 2018) might be of particular interest, as such an interconnectedness would facilitate transition to cooperative, sharing, circular firm networks.

In addition, the idea of ‘‘meta-networks’’ from research on forests also provides another interesting avenue for future research. Such meta-networks are a series of hierarchical, interacting networks and have been found to play an important role in forest resilience, when disturbance thresholds are crossed (Simard, 2009). Again, the linkage to recent research on industrial symbiosis, and here particularly to resilience of self-organized industrial ecosystems (Ashton, Chopra & Kashyap, 2017) would be interesting for future research.

This research concurs with the notion that in order to reach a sustainable future, a systemic approach is needed and latest ecological knowledge needs to be incorporated into economical models and systems (Murray et al., 2017). The biomimetic principles presented in this research will hopefully serve as stepping stones to facilitate development of circular value systems in business ecosystems, looking beyond the trees and seeing the forest with its underlying decomposer network, managing both information and material flows.

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TABLES AND FIGURES

Table 1 – Comparison of roles between natural networks and the business ecosystem

Role	Natural networks	Business Ecosystem
Producer: Take sunlight and use the energy to make sugar	Any kind of green plant	Mining (primary); manufacturing (secondary)
Consumer: Feed on producers or other consumers to survive	Predator animals	Wholesalers (primary); retail (secondary); end-customers (tertiary)
Scavenger: Contribute to decomposition by breaking them in to small pieces of organic material	Animals feeding on dead animals or dead plant matter	Dismantling, sorting, transportation of used materials
Decomposer: Release the organic and inorganic molecules in the form of nutrients for the plants and animals	Bacteria and fungi	Transformation of used materials back into the system

Table 2 – Comparison of ecosystem variables

	Natural Ecosystem (e.g. forest ecosystem)	**Current Business Ecosystem**
Roles of Agents/ Actors[a]	Balance of • producers (plants), • consumers (predator animals) • scavengers (animals that search and feed on carcasses or parasites) • decomposers (bacteria and fungi; brokering information and resources among actors within the system)	Dominance of • primary producers/ extractors (mining companies) and • secondary producers (manufacturing companies). • consumers (wholesalers and retailers) Lack of • scavengers (dismantling, sorting and transporting firms) • decomposers (transform or recycle used resources back into the system as (partly) “new” materials
Structural Characteristics	• Horizontal, vertical and spatial complexity • Dense • Decentralized • Interdependent • Heterogeneous:	• Horizontal, vertical and spatial complexity • Sparse • Centralized • Independent • Homogeneous
Co-Evolution (of Actors and the System)	• Equilibrium State: Equifinality and permanent adaptation • Non-Linear Change • Non-random future through continuous evolution	• Equilibrium State: Quasi-Equilibrium • Linearity: Predominantly mechanistic and linear, only recently non-linear evolution within networks • Non-random future through continuous evolution
Internal Mechanisms	• Emerging and self-organizing • Reciprocity and circularity • Openness • Connective	• Hierarchically governed • Causal and deterministic • Separation • Encapsulated

Table 3 – The biomimetic principles' main relation to specific ecosystem variables from literature

Main Ecosystem Variables	**Case Data Along Ecosystem Variables**	**Corresponding Biomimetic Principle**
Roles of Agents/Actors Producers; Consumers; Scavengers; Decomposers	Both FBBasic and the producers explain that the reverse logistics part is currently missing in order to recuperate materials, indicating a lack of scavengers and decomposers in the business ecosystem. The producers highlighted the importance of having reversed logistics and being able to disassemble their products into materials with a grade that can compete with virgin materials. Due to a lack of availability of such services on a larger scale, e.g. Tarkett and Interface both developed own solutions to recuperate the resources in their products. **Coding:** Scavenger, decomposer; reverse logistics.	Principle 1: In order to transition to a circular value system, the ecosystem needs an appropriate balance of actors.
	In analogy to the fungi network, FBBasic illustrates how it acts as a both the provider of the information about where resources are currently allocated/bound (in finished products) as well as providing the reverse logistics service to reverse material flows for disassembly and new allocation. **Coding:** Decomposer; brokering; reverse logistics.	Principle 2: In order to transition to a circular value system, decomposers need to manage information and material flows in an integrated way
	The producers interviewed highlight the current lack of reverse material flow providers and how they strive to make their products more "decomposable". All producers interviewed highlighted how they strive to come to full or nearly full circularity of their products by design. E.g. Emma Safety Footwear mentioned that when they are designing a product, they have three elements in mind: 1) safety, 2) comfort and 3) circularity. **Coding:** Producer; reverse logistics.	Principle 3: In order to transition to a circular value system, producers should have their outputs designed for reversed material flows
Structural Characteristics Horizontal, vertical and spatial complexity; dense; decentralized; interdependent; heterogeneous;	Both FBBasic and the producers highlight how a circular value system is industry boundary-spanning. The resources can flow not just within one area of application, but – in analogy to the fungi network – inter-species. **Coding:** Horizontal, vertical and spatial complexity; dense.	Principle 4: In order to transition to a circular value system, secondary material flows need to continuously cross industry boundaries
	Both FBBasic and the producers highlight the need for the right partners within a dense network, who have complementary capabilities. Both FBBasic and the producers here highlight that smaller, entrepreneurial market actors can be particularly innovative in their approaches. As Interface mentioned, larger more established suppliers might even be reluctant to try something new in comparison to more entrepreneurial partners. In order to identify complementary partners, the interviewees highlighted the role of networking events around the circular economy theme. **Coding:** Dense; heterogeneous.	Principle 5: In order to transition to a circular value system, network density between heterogeneous members is needed
	Both FBBasic and the producers interviewed highlight the current lack of reverse material flow providers and the need for decentralized information. As FBBasic illustrates, blockchain technology can be used to achieve the goal of a ubiquitous, transparent material passport. **Coding:** Decentralized; information flow; material flow.	Principle 6: In order to transition to a circular value system, the ecosystem needs reliable, decentralized information storage.

Table 4 – The biomimetic principles and empirical illustrations

Principles	FBBasic	Tarkett	Interface	Emma	Havep
1: Balance of Actors	""[…] from a manufacturer point of view or distributor point of view they are a bit afraid of setting up their own reverse logistics system or their identification system. So, on one hand they are really willing to develop and implement circular products but let´s say the circular system for that they are a bit afraid. So, to help them I said 'okay, then now we will develop it for you'."	"Anybody with a flooring needs to get rid of the flooring. What do you do when you want to get rid of the flooring? You put it in a container and call the local waste management company. We have a program out there that says okay you can call either a waste management company or you could also call us […]. We know we are being actively approached by our customers. Or even customers from our competition."	"It´s really nice that you use the word scavengers, because our CEO likes to refer to us as scavengers. But I fully agree that the decomposers are lacking."	"a very important [project] is arranging a circular system. So, that includes the reverse logistics and the next used application and the material passport."	
2: Integrated Material and Information Flows	"So, in the end we try to establish a system […]. Let´s say a virtual infrastructure and a physical infrastructure of connecting supply cycles. We call that intelligent materials pooling." (FBBasic)	""We have a program out there that says you can call either a waste management company or you could also call us […] You first want to have your process in place. To be sure that it is solid that you don't lose money on it. […] we also could make it cheaper for the customer that has a waste stream to call Tarkett [than to dispose of it as waste]."	"The reverse flows are just managed by our logistic departments as well. [But] reverse flows always are a little bit more complicated than outwards going flows which is really weird. [A few years back the first large lot of carpet tiles] we got from a customer in France […] was at customs for a few months, because somebody ticked the box waste, so we were not able to ship it back."	"[FBBasic] is closely located near our factory […] COFA does reverse logistics [and] they are creating material passports for us"	"[In addition to the reverse logistics, it would be great to have a] material bank, instead of money you have your resources in it. And that it is going back and then going forward and then coming back and has some kind of money value. It is something that has a big appeal for us. "

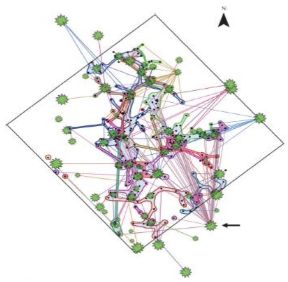
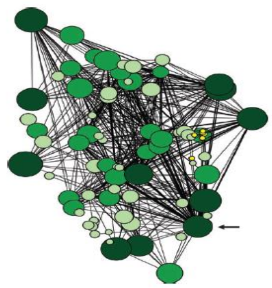
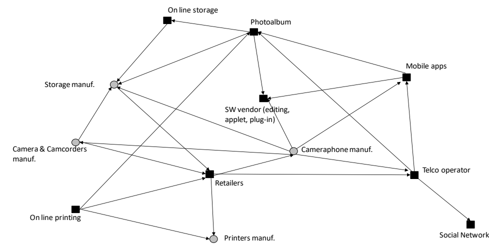
Principles	FBBasic	Tarkett	Interface	Emma	Havep
3: Decomposable Product Design	"We are working on the circular safety shoes and we want to have a head start with that. Let's say a head start [of] about 2 or 3 years, but of course it's also in the interest of the shoe manufacturers that its competitors will start to develop these kinds of products as well. Because then you can mass produce. We also have now these first circular safety shoe also with a reverse logistics system behind it and we say to our end customers, please also give your other labels shoes also to us. We will make sure that they get a proper next use application and then from this point of view we try to challenge also the competitors of my customer, also that they say 'okay, can we join the system'. Because it's in the interest of everybody."	"[We need to make sure that] the value of the product of Desso recycled is higher. And that can be obtained by the use of materials in the beginning that are keeping their value over time in multiple cycles. [So we came up with solutions so that] the materials that we extract can be used one on one in new carpet tiles which cannot be done with Bitumen because […] it is degrading over time. So that is certainly something we used. [We] phased out more and more polypropylene products in favor to polyamide products because polypropylene has no value whatever after it has been recycled."; "This is why Desso developed a new backing to replace the traditional bitumen backing […] with disassembly and recycling in mind […] This results in a continuous technical cycle, where old carpet is turned back into new carpet, again and again and again. […] The footprint is a positive, creative one."	"we also have been focusing on how to already design our products based with recycled and bio-based materials for which we of course had to work with our suppliers."	"When we are designing a product, we have three elements in mind. That´s safety, comfort and circularity."	"And you produce your product in a different way. So, you design it to recycle."

Principles	FBBasic	Tarkett	Interface	Emma	Havep
4: Cross-industry material flows	"…when you go […] from fossil to urban mining, […] polyamide out of shoe or the polyamide out of a carpet doesn't have to […] be reworked in the same application. So, the polyamide out of a shoe can be applied into a carpet or in engineering plastic […] As long as it complies to the circular principles, so let's not add new toxicity to it […] but if it's a polyester-cotton combination, use a polyester binder to make a construction material out of it. So, then you make a linear product into a circular product. […] This way of thinking… of connecting."; "One of the […] pitfalls in thinking in circular economy systems [is] that the people think a product has to become the same product again. Of course, that´s not necessary. Because when we look at primary raw materials […] you find some raw materials, and then you try to find a recipe to make a product out of it. It could be all kinds of products. […]Aluminum has a lot of applications and things like that."	"Millions of square meters of worn-out carpet are thrown away every year. Often being dumped at landfill sites. […] Desso offers clients a take back program to ensure the product will be recycled according to the Cradle-to-Cradle principles. Products will be taken back by Desso after their useful life, and will be safely recycled into new carpet products, or used in other recycling initiatives. Besides its own products Desso also encourages international collection of all types of used carpet, except for carpet containing PVC. [And they] separate the yarn and other fibers from the backing, producing two main material streams which can each be recycled. […] Cradle-to-Cradle design is inspired by nature, and sees carpet as being made up of nutrients, that should consistently remain in use, in an unending cycle."	"we refer to […] a supply web. […] from an input perspective a very open system. But on the other hand, you also need to close it from a take back perspective…But for me that doesn´t necessarily have to be in your chain. But you need to organize it. Either within your supply chain or with another sector or with this in between partner. So, [it's like a circular] web."	"we work with another workwear company, because they also work in a circular way and fully dress an employee in a sustainable way. The thing is that when [COFA, the reverse logistics branch of FBBasic] collects, [it] not only collect shoes from other companies but can also put in helmets or work wear or glasses. That's very good for the clients to have one [party bundling volumes]".	

Principles	FBBasic	Tarkett	Interface	Emma	Havep
5: Dense networks with heterogeneous members	"[…] you can see how we are connected to other activities because I work together with let's say more than ten also relatively small companies. We call ourselves the next generation coalition in the sense that lot of my partners also have been working in corporate surroundings and we all say, well you don't need the corporates anymore because we are able to offer corporate solutions without being a corporate […] For example, when I´m working on circular products with let's say a producing company and in their production facility, they also have an energy question. I´m not knowledgeable on energy, but I have a partner who is really knowledgeable. And so, now we are working on energy positive production facility for safety shoes."	"[I]n the cutting edge of sustainability you find less and less companies. If you find companies the people that are there usually are passionate about things. Either about their own company or about what they´re doing. But the point is that they at least have either something to tell or want to learn from [you]. […] I think the best allies are in certain suppliers [who are often] startups or fairly new companies that are coming with great ideas."	"Interface is actually running a business as an eco-system which means that this is something you need to do together with all stakeholders"; "if you want to close the loop you need [suppliers and customers]. But if you look at the circular economy perspective there are a lot of possible in between partners which can help […] And also, in various other countries we have contacts with smaller organizations. Because working with those people locally helps us to reuse the product locally as well. So, the specialized cleaning companies and the installers which also deinstallers are just as important. So, I would say the whole supply chain and any other stakeholder from other sectors which can be of use keeping products into the loop as a product or a material."	Sent their stakeholder map with a very diverse range of participants, e.g. dealers and end-users of the shoes, NGOs, government, suppliers, employees.	"Well, we see sustainability is something that you cannot do alone. We had to build partnerships with around twenty organizations that help us on different levels. [FBBasic] is one of the entities that is helping us."

Principles	**FBBasic**	**Tarkett**	**Interface**	**Emma**	**Havep**
6: Decentralized information	"The owner of the bicycles puts the bicycles batch or bicycles into the system. Whether new bicycles with a passport [...] or used bicycles […]. Then we say 'okay, it's a metal-plastic combination'. And based on the passport […] [t]hese are the materials that are in it. [Then] the owner decides to keep the bicycles in the system [either as bycycles to sell or] [a]fter 3 month [decides that]of these 100 bicycles [he cannot sell 50 and wants to disassemble them] into spare parts. Within another 3 months, [when] not able to sell these spare parts [they are] decomposed further physically […] into plastics, metals and whatever. And in our system, you can count up. […] how much aluminum do I have in my field…in my space in this system. Let´s say I have 10 tons of aluminum in crude, in spare parts and in bicycles."; "[…] traceability is very important and keeping quality in sight. […] For that reason, we say there is no use in developing a circular product without a circular system. And one of the elements in the circular system is identification. We have to connect it to blockchain again -- maybe blockchain could help to speed up the circular economy […] identification of the product and traceability of the product that´s very important. Because otherwise it will lose its value and it will be a mixed into the noncircular products then you lose value. We also developed a materials bank for secondary raw materials […]"	"I think a major barrier is the fact that REACH and customers are asking around chemicals, materials and compositions of our products […] My clients specifically in the States ask for transparency around used chemicals. The question that arises then is: How am I able to create this transparency if I just recycle stuff? If I just purchase whatever it is on the market and put it in my product. I cannot give that transparency. And that also means that I cannot give the guarantee to my customers […] that my product is safe if I don´t know what´s in there. […] I do believe that we can resolve this question by creating a flow of information in geography and in time. Some call it a product passport, raw material passport."	"we really believe that these environmental product declarations are crucial to have [stored in an openly accessible way] that you know what is in the product. [Then it's] easier to match material streams. Because the appearance of a product can be very different. We wouldn´t have thought initially that a fishnet would be made of the same material as a carpet tile"	"We have a QR code on the shoes that you can just scan with a special MIF. And the MIF is available on the app store. So, if you scan the QR code you can already see what materials have been used in that specific product. But we also want to extend this information. And we also want, for example, show the environmental impact"	"We have one product which is a jeans, a denim product, that has kind of a passport. [similar to FBBasic's] and it calculates the footprint on the entire product. And it traces back [the material origin]. [But] that if we sell it and it comes back that part is still not ready [but we need to finish it].".

Figure 1 – Visualization of natural and business ecosystems

<table>
<tr><th>Mapping of forest ecosystem relationships (e.g. Beiler et al., 2010)</th><th>Mapping of business ecosystem relationships (adapted from Battistella et al., p. 1203)</th></tr>
<tr><td>
• Here, the mapping shows the "top-down spatial typology" (p. 546) of a species of trees (green) and fungus (black) in a 30 by 30 m plot.

• Here, the mapping shows a "spatially explicit network model, showing linkages" (p. 549) between trees (circles), the lines indicate repeated links through multiple fungi connections.</td><td>

• Here, the mapping shows "the tangible relationships among the actors of the digital imaging ecosystem: the arrow show the direction of the money, whilst the opposite is the direction of product/service" (p. 1203)</td></tr>
</table>

Figure 2 – FBBasic's view on "Closing circles with the right partners" (Adapted from FBBasic company material)

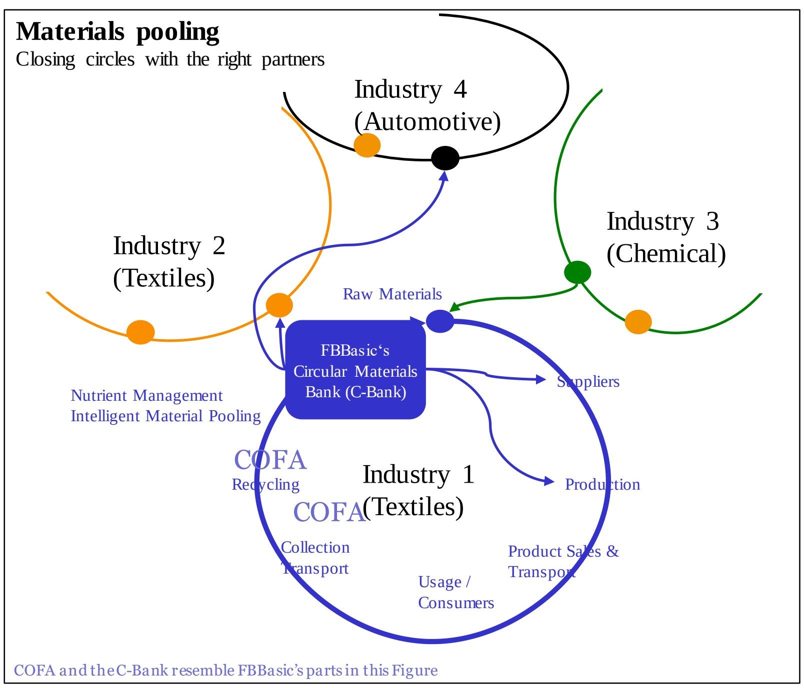


Figure 3 – Fungi network illustration by Gorzelak et al. (2015: 3) versus FBBasic

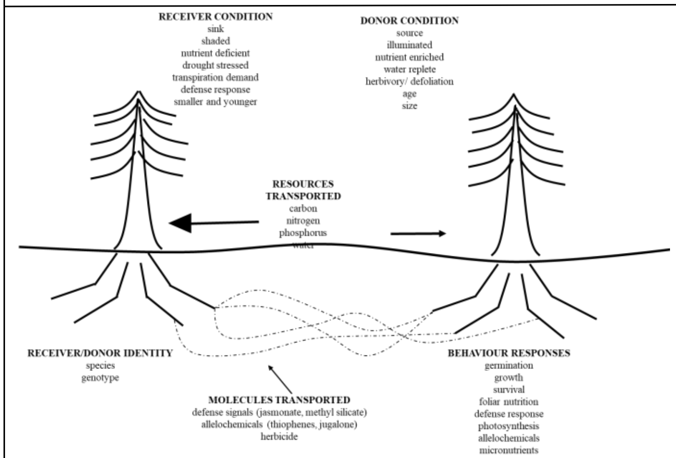
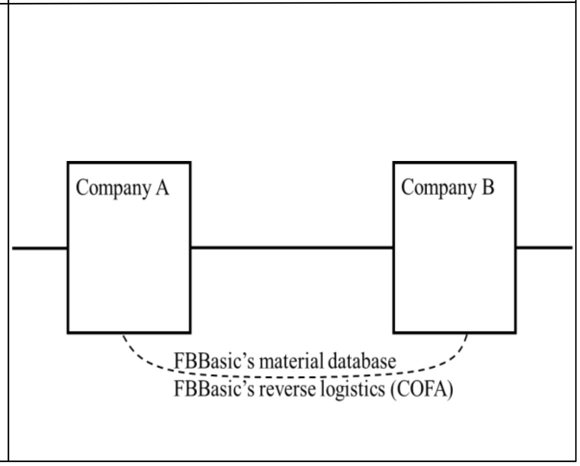
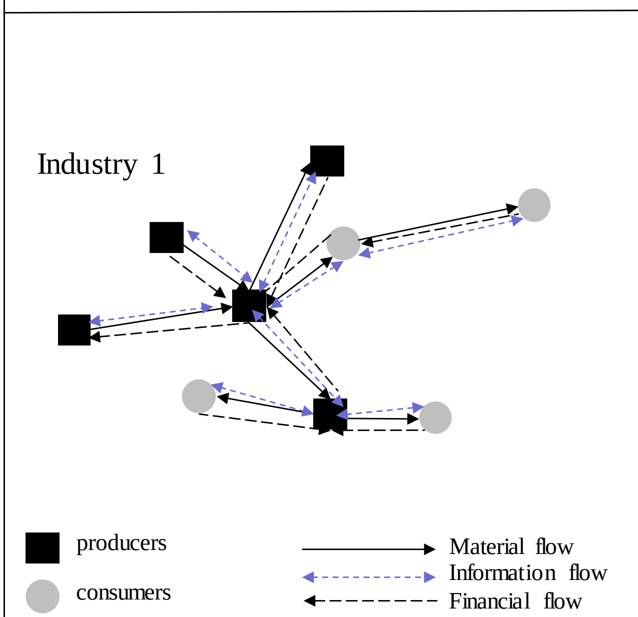
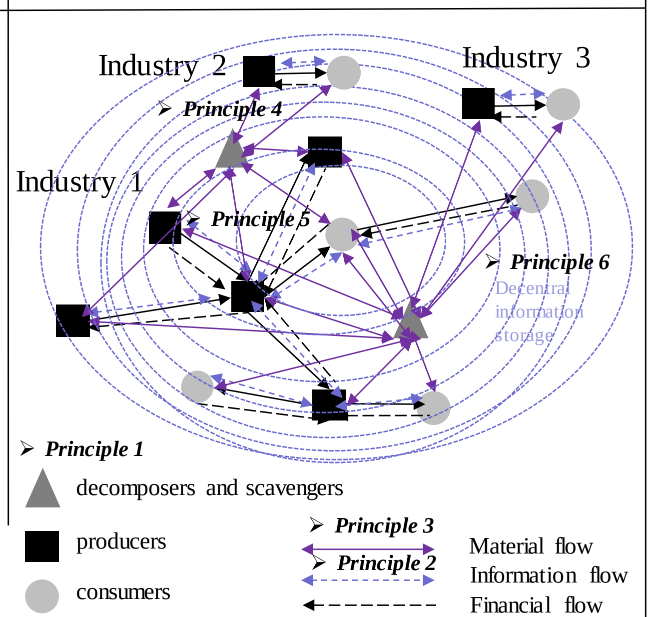
Fungi network illustration (adapted from Gorzelak et al., 2015, p. 3)	FBBasic's network illustration
	

Figure 4 – The current versus the future way of seeing business ecosystems: Creating circular value systems

Schematic business ecosystem view (current)	Schematic business ecosystem view (proposed)
	

APPENDIX

Appendix A - Interview guide for FBBasic (others were adapted based on this one)

Background Questions

1. State your name and describe you position in the business and how long you have been part of this business?
2. What is your professional background prior to joining/establishing this business?
3. Describe the structure of the business (if possible, then provide an organization chart) and discuss how the different businesses are connected.
4. Approximately how many employees are involved in the business at all locations?
5. How did the idea behind FBBasic come up?
6. When you consider the topic of "circular economy", what does it mean to you?
7. What do you think are primary barriers to establish a "circular economy"? Do you see a relation to FBBasic?
8. Do your see any areas of the economy as being better suited for adoption of "circular economy"? Why?
9. How would you describe the intended change in terms of:
   a. Technology and infrastructure?
   b. Behavioral and mindset changes of the market participants?
10. How would you visualize the current state and the target state of our economic system?

Understanding Goals and Performance

11. What is the "vision" of your business and how do you define "success" in your business?
12. Can you describe the environmental, social, economic impacts of your business? What exactly are the tangible and intangible improvements to nature, society and profitability? Do you try to quantify those (in future)?
13. Do you consider the success so far as sustainable?
14. What do you see as the primary barriers to success?
15. Were there differences between the planned and actual outcomes so far? How were these differences addressed?
16. To what extend are you relying on radical innovation in your business model and the way your network members do business? Where do the innovations arise?
17. To what extend are you relying on incremental improvement in your business model and the way your network members do business? How are the linkages established?
18. How do you combine and accommodate continuous improvement with radical change? When does the material reach the end of the cycle?

Understanding the System/Network Structure

19. Describe in your own words the value proposition. What do firms miss that they can find in your offering and what do they particularly appreciate? Why? [goal: understand why the nodes want to connect to FBBasic, for lack of what and for gain of what?]
20. Who are your primary suppliers? Are you aware of your suppliers' suppliers? [Question for the network members, not for FBBasic]
21. Who are your major customers? Are you aware of your customers' customers? [Question for the network members, not for FBBasic]
22. Who are your major network members? Are you aware of these members' customers and suppliers? [Question for FBBasic]
23. Can you draw a map of these major actors within your network?
24. How diverse can the businesses participating in your network become? .)?

   a. Do they have to fulfil any standards or can anybody participate?
   b. How do they enter and do they get different customer statuses (e.g. basic, advanced etc.)
25. What are the processes for cataloguing materials and what are the processes for running the market place? Are there specific use cases for each?
26. What is the level or circularity within your network and where does it occur?
27. How is the reverse flow organized and how are the information, material and financial flows managed?
28. Discuss the stakeholders that are directly or indirectly involved in the business.
29. Who (else) has helped/played a major part in establishing the business?
30. What are the primary facilitators of success?
31. Whom from your "business system" would you regard as "key stakeholders"?
32. Whom from your "business system" would you regard as key informants for this research (whom would we have to talk to get a perspective from the main parties that form the "supply system")?
33. How has the network adapted and how do you drive growth of the network? [complex adaptive systems]
34. How do you see your role as an information broker in the network? Are there other network members that are taking over a brokerage role? Can you see the development of sub-networks that concentrate on certain types of material supply (or transactions)? [nexus broker]
35. How "open" versus "closed" does the network need to be from your perspective? How adaptive does it need to be?

Understanding specific areas of application

36. Can you describe the flow of materials and information in both the protective clothing and bicycle industry? Please include in the discussion reverse flows, supplier and customer participation? (Anything that you can do to help us visualize the network/system?)
37. How does the market for recycled or reused materials/goods operate?
38. You mentioned the protective clothing area – how do you aim to challenge and change the current status quo (in the textile industry)?
39. You mentioned the protective clothing area – with whom do you aim to change the current status quo?
40. You mentioned the protective clothing area – how has the project progressed so far?
41. You mentioned the bicycle industry – what is the current situation of proposing a new model there, too?
42. Are there any other current projects of yours that could be relevant/helpful for this study?
43. How do these projects interconnect in the wider network perspective? Can you envision the integration and interconnection of previously nested/isolated networks to suddenly open up to each other? Who should be bridging and steer this integration process and the daily business process that hopefully emerge?
44. How do the materials shift between networks?
45. What are the advantages of your network compared to existing reverse logistics approaches by manufacturers?

Material Flows

46. Discuss how material flows are meant to change based on your business.
47. How much waste is there in the system? Where are the "weakpoints" for the waste?
    a. What happens to the material flow when there is a disruption?
    b. Can you gain economies of scale?
48. Do you see potential for further waste reduction by establishing circular flows? What are the main prerequisites that need to be fulfilled to increase the circularity in the network?

49. Discuss how materials are viewed in your business model (e.g. value of primary versus secondary materials).
50. How do you see the developments of resource shortage and increasing resource disruptions in primary material flows?
    a. How do these topics affect FBBasic?
    b. Are the current project partners aware of these topics?
51. How do you see the topic of transportation costs ?,(i.e. sourcing recovered materials nearby vs. sourcing new raw materials from further away)

Financial Flows

52. Discuss the relevance of flow and frequency of both upstream and downstream financial flows for establishing sustainable supply systems.
53. How does the relative relevance and role of banks change?
54. Which role does trust play in sustainable supply systems?
55. How would the value of the materials be established?
56. How much do the number of cycles a material already went through influence its value?
57. Where would it be more beneficial for manufacturers to procure new vs. recovered materials? How could that be changed in favor of circular flows?
    How would the circular recovered materials be valued considering dynamics existing in primary material markets (supply / demand, weather, currency etc.)

Information Flows

58. How does your technical solution ensure that information is stored decentrally and remains accurate of time?
59. Describe and discuss the flow of information both upstream and downstream with your stakeholders as part of your business model.
60. How does the information flow across the network, both upstream and downstream?
61. What types of information are shared?
62. How often is that information shared?
63. How are materials linked to the catalogue?
64. What have been some of the technological challenges you have encountered?
65. How does the product information play a role in establishing sustainable supply systems?
66. How do new members identify your offering and/or how are you identifying them?
67. Does FBBasic also intend to do a “matchmaking” of resources, beyond offering the material database, i.e. actively engage in brokering? [
    a. Or is it focused on establishing the infrastructure so that supply and demand can find each other transparently?
    b. Or some other form of orchestration?
68. Do you consider that once your material database is in place there might be some self-organization of participating businesses around a more circular business approach?

Wrap-up

69. From your perspective, is there anything that we should have asked about that we didn’t that might be relevant for the research?
70. With whom should we best talk next?
71. Could you facilitate to set up interviews with them (e.g. we prepare an information email to be forwarded)
72. As additional questions arise, how can we best follow-up with you?