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Made to break? A taxonomy of business models on product lifetime extension

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ABSTRACT

This paper contributes to the establishment of product lifetime extension (PLE) as a field of study through development of a framework of product lifetime extension business models (PLEBM), and offering of a taxonomy of PLEBM. The proposed taxonomy of PLEBM draws systematically on characteristics of 150 organizations which are identified in the scholarly and managerial literature as engaging in PLE. By considering the full spectrum of PLE practices systematically, we delineate these organizations on seven dimensions (i.e., key activities, key partners, channels, customer segments, customer relationships, offering, and revenue streaming) with 30 corresponding literature-based features. A clustering procedure, with key activities and key partners as input variables, revealed seven mutually exclusive PLEBMs: Relational product-as-a-service, Brick&digital product nurturers, Quality product designers, Secondhand vendors, Marketer-managed access systems, and P2P access brokers. Overall, product nature improvement through design is found less prevalent than product nurture strategies, such as maintenance (maintenance/advice/training/consulting), recovery (remanufacturing and repair), redistribution and access schemes. This study also presents a state-of-the-art overview on how organizations and consumers extend (pro-)actively product lifetimes.

1. Introduction

Product lifetime (PL) is "the duration of the period that starts at the moment a product is released for use after manufacture and ends at the moment a product becomes obsolete beyond recovery at product level" (Den Hollander et al., 2017, p. 519). PL is therefore the useful life of a product; the time during which the product remains integer and usable for its primary function for which it was conceived and produced (van Nes and Cramer, 2003). Products can have one or more use cycles, but only one lifetime (Den Hollander et al., 2017). PL extension (PLE) refers therefore to the use cycle(s) that occur during a PL which reverse the product's obsolescence.

Undue shortening of product lifetime increases waste and contributes to serious environmental threats in many advanced and developing economies (World Bank, 2018). Organizations, through planned obsolescence (Pope, 2017; Rivera and Lallmahomed, 2016), and consumers, through psychological obsolescence and subsequent throwaway behaviors (Packard, 1968), are blamed for shortening of the PL. Nevertheless, organizations and consumers do also engage, separately or together, in innovative PLE efforts through various business models (BM) (The Ellen MacArthur Foundation, 2015; Urbinati et al., 2017; Lüdeke-Freund et al., 2018). For example, the partnership between Patagonia and eBay is a corporate initiative relying on consumers to donate or resell their Patagonia clothes online (Bocken and Short, 2016). Ikea's "Second Life for Furniture"[1] program is contingent on consumers to trade in old items in return for a store voucher (Ertz et al., 2017a). Other examples include auctions, antiques, swap meets, secondhand stores, charities/donation centers, flea markets, garage sales, inverted logistics, design for longer life, rebuy/recommerce systems, trade-in schemes, remanufacturing and reconditioning; all of which have been studied in sociology, anthropology, marketing,

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[1] https://www.ikea.com/gb/en/this-is-ikea/people-planet/energy-resources/waste/.

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geography, industrial ecology, or cultural studies, among others.

The above examples indicate that PLE business models (hereafter, PLEBMs) are highly diversified, and are studied across different literature streams, research fields, and disciplines, albeit independently. Consequently, the literature on PLEBMs has evolved in a fragmented manner, resulting in distortion of the actual breadth and scope of PLE in the economy. A symptom of this distortion reveals itself in attribution of more prominence to planned obsolescence (e.g., PLATE Conference 2017) than PLE. This bias could be rectified by a systematic analysis of PLEBMs with an integrated and holistic approach. The current study offers a step in this direction. We bring PLE efforts to the fore, focus attention on what works to extend PL, and how PLE efforts may be further developed and enhanced.

Using the business model (BM) framework (Lewandowski, 2016; Osterwalder and Pigneur, 2010), past research focused, either on classifying circular/sustainable BMs (e.g., Bocken et al., 2014; Gaiardelli et al., 2014; Lüdeke-Freund et al., 2018; The Ellen MacArthur Foundation, 2015; Urbinati et al., 2017), tapping inevitably into some PLE forms, or on classifying specific PLE models (such as, reuse [Whalen et al., 2018]; or, product design [Den Hollander et al., 2017]). Few studies focused on classifying PLEBM exclusively. Even fewer encompassed the full spectrum of PLE practices holistically, ranging from product design (Bakker et al., 2014a, 2014b), to redistribution (Bakker et al., 2014b; Cox et al., 2013). This study advances these latter efforts. Considering the full range of PLE practices, we offer an integrated and systematic analysis of organizational PLE efforts.

Our study intends to address the voids in the literature and contribute to scholarly research on product lifetimes in several ways. First, adopting a positive science perspective (White, 1992), this study focuses on what works (in terms of PLE strategies), and how it may be developed even further rather than focusing on what does not work (i.e., planned obsolescence). This perspective is more interesting than an exclusive focus on planned obsolescence because it could yield powerful insight for benchmarking, gap identification-exploitation, and BM prototyping (Hartmann et al., 2016). Second, this study offers a state-of-the-art overview on how organizations and consumers extend (pro-)actively PL. Third, this research adapts the BM framework (Chesbrough and Rosenbloom, 2002; Osterwalder and Pigneur, 2010) to identify the structure underlying the full range of organizational PLE practices in order to systematically describe and classify organizations in a taxonomy. Fourth, this study classifies the broad array of PLEBMs cited in past research according to their key PLE activities and key partners in those activities. This classification provides practical generalizations, benchmarking, and BM prototyping opportunities to organizations, particularly small- and medium-sized ones. Using insights from the classification scheme, organizations can articulate their value proposition and design more effective value creation and value capture processes to integrate PLE in their business models.

Starting from the premises above, this paper develops a taxonomy of PLE business models (PLEBMs) by taking a snapshot of full spectrum of PLE implementations cited in the literature. We aim to address the overarching research question: What business models manifest themselves in companies that consider PLE as an important value creation practice (key activities)? Specifically, we conduct a systematic analysis of PLEBMs and identify clusters of organizations with similar BM. We thus contribute to research by providing a holistic and systematic understanding of current PLEBMs by uncovering clusters of similar PLEBMs and delineating them in detail. We also create some reference points for future research regarding the importance, success, and evolution of different types of PLEBMs.

2. Literature review

2.1. Product lifetime and product lifetime extension

Product lifetime (PL) is distinct from product economic life, which refers to the point when maintaining a product is more expensive than replacing it (Heiskanen, 1996). PL differs also from product technical life, or “the maximum period during which [a product] has the physical capacity to function” (Cooper, 2010, p. 9). The technical life conflates with the notion of “functional life” of the product. The functional life of a product is the time a product should last regardless of external intervention to increase its lifespan (Cox et al., 2013). The functional life refers to product design for making products that last longer (Cox et al., 2013; van Nes and Cramer, 2003). Bakker et al. (2014a) mentioned improved design as a strategy to make products that last, to optimize the “nature” of the product. This aspect of PL is strongly related to manufacturers, and has been based on innovation, technology, processes and systems approaches (van Nes and Cramer, 2003). PL is also the result of actions and practices that enhance the characteristics and functionalities of products, what Cox et al. (2013) call “nurture”. Bakker et al. (2014b) mentioned several PLE strategies that “nurture” the product, including refurbishment and remanufacturing.

Therefore, PL is “an outcome of ‘the nature’ of a product (functional life) and its ‘nurture’ (lifetime in use) by consumers” (Cox et al., 2013, p. 21). It follows that PLE encompasses behaviors, processes, systems, and procedures by consumers or organizations, contributing both to product “nature” and/or “nurture”. More specifically, PLE strategies enhance the useful life of a product, in design (i.e. nature), as well as through maintenance and prolonged use with a consumer or potentially across a variety of idiosyncratic contexts and actors (i.e. nurture) (Cox et al., 2013). During this journey, the product remains whole, and geared or usable for the primary function for which it was originally conceived and produced (Cooper, 2010). However, PLE excludes end-of-life treatment in the form of reutilization of materials through recycling, for example (Den Hollander et al., 2017).

This perspective on PLE extends previous definitions offered in the circular economy literature that take the organization as vantage point (e.g., Bakker et al., 2014a,b; Lüdeke-Freund, et al., 2018; Urbinati et al., 2017; Whalen, 2017). For example, Bakker et al. (2014a) stated that PLE and value preservation are achieved through design for long life/repair/remanufacturing, refurbishment and remanufacturing. This conceptualization is tangential to ours since improved design contributes to nature, and refurbishment/remanufacturing contributes to nurture. However, our conceptualization goes beyond corporate realm by acknowledging consumer exchanges and collaborative practices such as reselling, donation, bartering and temporary disposal through lending/leasing/sharing as significant PLE strategies to nurture products (Belk, 2014; Perren and Kozinets, 2018). Furthermore, our conceptualization shares some but not all aspects of sufficiency-driven BM, which focus on moderating consumer demand (Bocken and Short, 2016). Our conceptualization overlaps with all actions and practices of sufficiency-BM with direct impact on either the nature or the nurture of the product. For example, Bocken and Short (2016) recommendation to “making products that last longer and avoid built-in obsolescence” (p. 41) refer to improving the functional life or nature of the product and conflate with PLE strategies. However, “curbing demand through education and consumer engagement […], focusing on satisfying ‘needs’ rather than ‘wants’ and fast-fashion, conscious sales and marketing techniques, new revenue models, or innovative technology solutions” (p. 41) are not encompassed by our conceptualization of PLE. They refer to higher-order strategies, or meta-PLE strategies, as they do not directly

relate to product nature or nurture per se.

2.2. Product lifetime extension in the circular economy

The circular economy is also called a closed loop economy (i.e. cradle-to-cradle model) (Stahel, 2016). The 'loop' concept is tantamount to the circular economy paradigm. In fact, the circular economy suggests a redesign of the current linear economic system, based on 'linear resource flows', towards 'closed-loop resource flows' that eliminate waste from design to disposition (Stahel, 2016). PLE operationalizes in praxis these closed loops of product flows through nature and nurture.

The literature emphasizes two fundamental strategies towards creating closed loops of products (Bocken et al., 2016; Nussholz, 2017b; Stahel, 2016): (1) the *slowing loop*: prolonging useful life of products through design for long-life as well as life extending measures such as repair, remanufacturing, refurbishment, reconditioning, or reuse; 2) the *closing loop*: reutilization of materials through recycling. The product life cycle model comprises five stages: 1) material extraction; 2) material processing; 3) production; 4) use phase; and 5) end-of-life treatment. The circular economy literature suggests a variety of resource efficiency strategies pertaining to each of these stages (Nussholz, 2017a, p. 9). The closing loop corresponds to the "end-of-life treatment stage" which involves recycling or reutilization of parts or materials recovered at the end-of-use and reintegrated into the value chain for a new product (Wells and Seitz, 2005). Since PLE is not about recycling/reutilization, PLE does not fit in the stages of material recycling, material extraction and material processing of the product life cycle model.

Our conceptualization of PLE excludes the end-of-life treatment stage, consisting of recycling, and thus does not contribute to the closing loop of the circular economy. Instead, it contributes substantially to the slowing loop, particularly, in two distinct product-specific ways, namely through improving the design during the "production phase" of the product life cycle (i.e., nature strategies) (Nussholz, 2017a), and implementing activities, processes and systems that increase the "use phase" of the product life cycle (i.e., nurture strategies) (Nussholz, 2017a). In other words, PLE contributes to the slowing loop by "creating longer-life products" and "extending the product's life in use" (Bakker et al., 2014b). Table 1 shows examples of nature strategies such as improvement of the functional life of the product, from its inception through augmented design. Examples of nurture strategies refer to post-purchase processes that extend the lifecycle of the product, such as take back management, sharing assets (i.e. shared ownership and collaborative consumption), extended producer responsibility (e.g. extended warranty or maintenance schemes), as well as reuse, re-manufacture. Collectively, these examples demonstrate that PLE is nested within the circular economy.

2.3. Business model

A BM represents a set of strategic decisions that define how companies create, transfer and capture value through their internal activities and partnerships with stakeholders, such as suppliers and customers (Osterwalder and Pigneur, 2010). The BM supports management in defining and developing corporate strategy; for example, it defines the positioning in the market against competitors (Urbinati et al., 2017). In addition, the BM provides simple and powerful insight into the organizational structure and value creation processes of a company (Osterwalder and Pigneur, 2010).

We suggest that the analytical nature of the BM framework can advance PLE. In fact, the BM framework contributes compellingly to the objective of defining clearly how an organization converts resources and capabilities into economic value (Teece, 2010). While products are resources, the capabilities and processes used to increase the lifetime of these products can constitute a source of economic value. Hence, study of the organizational features that define various forms of PLE business models is not only useful to properly classify and identify (new) avenues for curbing product waste, but also to derive economic value out of these activities. Besides, several environment-focused scientific contributions have used it or discussed it in their analyses (Biloslavo et al., 2018; Bocken et al., 2014; Gaiardelli et al., 2014; Lüdeke-Freund and Dembek, 2017; Nussholz, 2017a, 2017b; Urbinati et al., 2017; Whalen, 2017). Indeed, as shown in Lewandowski (2016) review, the BM framework has been used extensively for classifying circular or sustainable business models.

The treatment of PLE in the past BM literature has been everything but holistic. On the one hand, the past literature includes taxonomies of BMs on sustainability or circular economy, some of which contain various PLE components, as shown in Table 1. Lüdeke-Freund et al. (2018) classify different circular business models that include PLE strategies. Bakker et al. (2014)a,b suggest a 'products that last' categorisation as part of the circular economy focusing indeed on extending the life of products. Bocken and Short (2016) and Bocken et al. (2016) propose a 'sufficiency business model' category, as part of the circular economy strategy, focusing on slower consumption (e.g. by making products that last), arguably also a product life extension strategy. Urbinati et al. (2017) create a list of circular business models. Whalen (2017) also lists circular business models that include 'extending product value'. Finally, Lewandowski (2016) applies the BM framework to classify circular business models. These insightful studies show that PLE lies at the core of the circular economy and of sustainability.

On the other hand, several classifications in the literature refer to very specific PLEBMs. For example, Gaiardelli et al. (2014) provided a much-needed classification of product-service offerings. However, their study focuses strictly on servitisation strategies, i.e. nurture strategies (Cox et al., 2013), drawing on the research stream of access business models (Mont, 2002; Tukker, 2004; Tukker and Tischner, 2006), but does not include product design (i.e., nature strategies [Bakker et al., 2014a]). Likewise, Whalen et al. (2018) customized and applied the BM framework to circular business models focused on PLE, but solely on reuse activities, thus excluding the product design strategies. Den Hollander et al. (2017) underscored the crucial distinction between eco-design and circular product design strategies. Their typology contributed to a deeper understanding of the role of product design, as a nature strategy (Bakker et al., 2014a). Yet, their typology did not integrate nurture strategies, such as product-service offerings or redistribution systems.

Moreover, most if not all of past topical research is based on qualitative methods such as case studies (e.g., Nussholz, 2017a, 2017b; Whalen, 2017; Whalen et al., 2018) or conceptual reviews (e.g., Gaiardelli et al., 2014; Lewandowski, 2016; Urbinati et al., 2017).

Whether framed in the general concept of circular economy or focused on specific research areas (e.g., product-service offerings), no past research has produced a typology of BM exclusively on PLE, while encompassing holistically the full spectrum of nature and nurture strategies (Cox et al., 2013) and using a quantitative approach. This study attempts to fill these gaps by developing a quantitative and inductive classification of PLEBM.

Table 1
Product lifetime extension business models and strategies in the literature.

Reference	Product lifetime extension facet	Product lifetime extension business models	Description
Sustainable business models literature			
Bocken et al. (2014)	Nature	Encourage sufficiency	Product longevity: Slower consumption by improving product design
	Nurture	Deliver functionality rather than ownership	Product-oriented product-service systems (PSS): maintenance, extended warrantee
			Use-oriented PSS: rental, lease, share
			Result-oriented PSS: pay per use
		Create value from waste	Reuse, re-manufacture, take-back management, and sharing assets
Gaiardelli et al. (2014)	Nurture	Product-service systems	Product-oriented PSS: maintenance, extended warrantee
			Use-oriented PSS: rental, lease, share
			Result-oriented PSS: pay per use
Circular business models literature			
Bakker et al. (2014a)	Nature	Design strategies for product life extension	Longer life products: To make a product last for several years
			Reparability: Self-repair and serviced repair made easy
			Refurbishment: Possibilities for refurbishing and upgrading (e.g. mid-life efficiency checks and replacements)
			Remanufacture: Need for collection from client
	Nurture	Access model	Allowing temporary access to products while retaining ownership
Bakker et al. (2014b)	Nature	Products that last	Designing products for longer life: design for: maintenance and repair; upgrading and upgradability; standardization and compatibility; and dis-and reassembly
	Nurture	Extending the product's life in use	Remanufacturing, refurbishment
Accenture (2014)	Nurture	Product as a service	Offer product access and retain ownership to internalise benefits of circular resource productivity
		Sharing platforms	Enable increased utilization rate of products by making possible shared use/access/ ownership
		Product life extension	Extend working lifecycle of products and components by repairing, upgrading, and reselling
The Ellen MacArthur Foundation (2015)	Nature	Optimise	Increase performance/efficiency of product
	Nature/Nurture	Share	Design for durability, upgradability, etc.
			Prolong life through maintenance
			Share assets (e.g. cars, appliances)
			Reuse/secondhand
	Nurture	Loop	Remanufacture products
Bocken and Short (2016)	Nature	Sufficiency business model	Product longevity: Slower consumption by improving product design
Bocken et al. (2016)	Nature	Classic long-life	Slower consumption by making products that last
	Nurture	Access and performance model	Allowing temporary access to products while retaining ownership
		Extending product value	Reuse, remanufacturing
Whalen (2017)	Nature	Extending the useful lifetime of products	Design for longer average lifespans
	Nurture		Access and performance model: Allowing temporary access to products while retaining ownership
			Enabling second life through reuse (i.e., repair, remanufacturing)
Urbinati et al. (2017)	Nurture	Reverse supply chain	Reverse logistics: inspection and revaluation of products' current state, redistribution/ reuse, and remanufacturing
Nussholz (2017b)	Nurture	Business interventions to embed circularity in a business model	Product collection and reintegration into the value chain.
			First sale: enabling prolonged useful life through design for longevity, repair or re-manufacturing of their products and offer repair or upgrading services.
			Additional sale(s) of the product or parts to the users.
Lüdeke-Freund et al. (2018)	Nature	Ecodesign patterns	Product design: Improved product design
		Service and performance patterns	Product-oriented PSS: maintenance, extended warrantee
			Use-oriented PSS: rental, lease, share
			Result-oriented PSS: pay per use
		Closing the loop patterns	Remanufacturing/Next life sales, repair, reuse, take back management, upgrading

3. Research methods

3.1. Overview of methodology

This paper aims at building a taxonomy of PLEBM. We develop a framework in three steps (Hartmann et al., 2016). In step 1, a systematic literature review revealed relevant BM frameworks and their corresponding dimensions (Bocken et al., 2014). We identified several features for each dimension based on a review of the literature in ecological production, green/ethical/responsible marketing, consumer behaviour, supply chain management, collaborative economy, and sustainability. The retained dimensions and corresponding features constituted our PLEBM framework. The features of each dimension serve therefore to describe PLEBM. In step 2, we performed the sampling of the organizations to be coded and classified. In step 3, we coded the organizations along the PLEBM framework. In step 4, we used cluster analysis to derive a taxonomy (Everitt et al., 2011) of PLEBM.

3.2. Step 1: the elaboration of the PLEBM framework

Although there is no established rule on the number or types of BM dimensions to use (Osterwalder and Pigneur, 2010), the following seven dimensions are found most commonly in scientific contributions: key activities, key partners, channels, customer segments, customer relationships, offering (also called, value proposition), and revenue stream. We thus retained these seven dimensions as building blocks in our PLEBM. The choice of specific facets for each dimension was based on the seminal literature (Osterwalder and Pigneur, 2010) which we adapted to the topic of PLE. For example, customer segments are typically considered as B2B or B2C in conventional markets as per Osterwalder and Pigneur

(2010) as well as in studies using this framework (e.g., Hartmann et al., 2016). Yet, there may also exist a C2C segment in the secondhand market, swap meets, or access schemes, for example. Since these types of markets contribute to extending product lifetimes by making the product usable to others, these types of practices contribute to PLE. Therefore, we needed to add a "C2C" facet in the customer segments dimension of PLE business models in order to describe them meaningfully and comprehensively.

Key activities. The key activities building block "describes the most important things a company must do to make its business model work" (Osterwalder and Pigneur, 2010, p. 36). For PLEBMs, these activities involve PLE processes, systems and procedures. Based on the literature, there are five overarching PLE activities (see Table 2). Improved product design enhances the "nature", or the functional life of the product, whereas the four other activities contribute to the "nurture", or lifetime in use of the product (Cox et al., 2013). The improvement of product and production processes as well as improved design for repair (Bakker et al., 2014b) were merged into "improved product design" given the overlapping nature of these features. Also, given the similarity of essence between maintenance, advice, training, and consultancy contracts, because they involve servitisation strategies (Gaiardelli et al., 2014), we grouped both under a single variable entitled "maintenance". Likewise, reparation and remanufacturing-related strategies (i.e., reconditioning, refurbishing, rebuilding) were both grouped under a single variable entitled "recovery", which conveys well the process of remedial actions restoring a product to its normal or previous status (Den Hollander et al., 2017). Finally, leasing, renting, mutualising and pooling were grouped together as "access schemes", as a reference to Bardhi and Eckhardt (2012) access-based consumption, whereas product transfer activities such as donation, swapping and secondhand marketplace were considered as "redistribution".

Key partners. Also called key partnerships, is a building block which "describes the network of suppliers and partners that make the business model work" (Osterwalder and Pigneur, 2010, p. 38). In many instances these are organizations. However, technological advances (i.e. web platforms, social media, mobile applications), have empowered consumers to source pre-owned products to organizations and other consumers (Belk, 2014; Ertz et al., 2017c). Therefore, key partners are either organizations or consumers, i.e. "peers".

Key activities and key partners were used as the main dimensions in PLEBM classification. First, each company conducts different activities to produce and deliver offerings (Hartmann et al., 2016). For PLEBMs, these activities inevitably relate to PLE practices as these are considered at the core of value creation. This is why key activities was selected as the first clustering variable. Second, since this paper seeks to highlight how consumers/peers themselves contribute to PLE, it was essential to choose a dimension, which reflects consumer product input in PLE activities. Thus, key partners formed the second clustering dimension.

Channels. The channels building block "describes how a company communicates with and reaches its customer segments to deliver a value proposition" (Osterwalder and Pigneur, 2010, p. 26). Table 3 provides a summary of the principal channels of relevance in the context of PLE. Since digital platforms may either allow commercial transaction or focus exclusively on content, it is important to make this distinction salient in the framework. We thus divided this facet into two sub-facets: transactional and interactive.

Customer segments. Customer segments "defines the different group of people or organizations an enterprise aims to reach and serve" (Osterwalder and Pigneur, 2010, p. 16). The most common classification differentiates businesses (B2B) from individual consumers (B2C) (Hartmann et al., 2016). We shall add C2B to the second category as peers may supply pre-owned goods. In addition, the digital economies revealed that many businesses enable C2C exchanges (e.g. eBay, Kijiji, Amazon, Peerby, Craigslist, Freecycle) (Ertz et al., 2018; Perren and Kozinets, 2018). The three features of this dimension are thus B2B, B2C/C2B and C2C.

Customer relationships. This building block "describes the types of relationships a company establishes with specific customer segments" (Osterwalder and Pigneur, 2010, p. 28). Past literature on product-service system identifies two main types of interactions, namely transactional or relational (Gaiardelli et al., 2014). Transactional refers to interaction only when a good or service is exchanged, whereas relational involves more frequent, customized and personalized interactions over the long-term, such as during training sessions, preventive or full maintenance services.

Offering. The product or service offering, also called the value proposition, "describes the bundle of products and services that create value for a specific customer segment" (Osterwalder and Pigneur, 2010, p. 22). The value proposition or offer is the value created for customers through the offering (Hartmann et al., 2016). According to Nussholz (2017a), a company's offering of PLE can be either core or secondary. When the offer is core to the organization, the PLE is explicitly and proactively incorporated. That is, the company explicitly positions itself as enabling the extension of product lifetimes. If PLE is secondary, it is an incidental outcome of organizational activities. That is, although the organization does not explicitly frame its BM as a PLE enabler, PLE is an inevitable and implicit consequence of its activities.

Revenue stream. The revenue stream building block "represents the cash a company generates from each customer segment" (Osterwalder and Pigneur, 2010, p. 30). Past research (Osterwalder and Pigneur, 2010) highlighted seven different revenue streams. We also include donation/crowdfunding since some digital platforms, enabling C2C exchanges, do collect money through such means (Perren and Kozinets, 2018). Features of this dimension are shown in Table 4.

We did not include the cost structure dimension due to difficulty in obtaining accurate and reliable information. Also, key resources were not included because in the case of PLE only one category (i.e., pre-owned products) would be relevant for all companies. Compiling the aforementioned seven dimensions and the corresponding thirty features leads to the PLEBM framework displayed in Fig. 1. This canvas is used to delineate BMs of the sample companies in a systematic and comprehensive manner.

3.3. Step 2: Sample and data collection

This study focuses on companies, which extend the lifetime of products through any or all of the four generic predefined PLE activities. Since there is no formal repository for such organizations, judgmental (purposive) sampling was used. First, the sample was drawn from scientific publications on PLE-related domains such as, among others, product-service systems (e.g. Gaiardelli et al., 2014), the collaborative economy (e.g. Belk, 2014), lateral exchange systems (Perren and Kozinets, 2018), remanufacturing and repair (e.g. Whalen, 2017), goods multiple lives practices (e.g. Ertz et al., 2017a, 2017b), circular business models (The Ellen MacArthur Foundation, 2015). We used the name of these domains as search terms in order to identify relevant publications (Hartmann et al., 2016). We then retained only those published no earlier than 2010. Two exceptions to this rule were Chu and Liao (2007) for *eBay* and *Gray and Charter (2006)* for *Milliken and Perkins Engines*. We retained these publications as all three businesses were still in operation at the time of the study. Importantly, the same companies appeared repeatedly across publications, demonstrating theoretical saturation in our

Table 2
Key activities.

Product lifetime extension facet	Activities	Sub-activities	Definitions	Representative studies
Nature	Improved product design (starting loop)	Improved product and production process	Use of more durable parts, components, and production processes	Nussholz (2017a); Bakker et al. (2014a), 2014b
		Improved design for repair	Better design for repair, remanufacturing, refurbishing, and reconditioning; Design for up-datable or up-gradable products that do not have to be replaced in their entirety.	van Nes and Cramer, 2003; Bakker et al. (2014b)
Nurture	Access schemes (slowing loop - prolonged use)	Access schemes (use-oriented service scape)	Leasing: the lessee pays a regular fee for unlimited and individual use of the product. Renting: the customer uses the product individually for a predetermined period. Mutualising: the product is sequentially used by different customers. Pooling: the simultaneous use of a product by different customers.	Mont (2002); Tukker (2004); Tukker and Tischner (2006); Gaiardelli et al. (2014, p. 513–515); Ertz et al. (2017c, p. 725); Ertz et al. (2017b, p. 4)
	Maintenance (slowing loop - prolonged use)	Maintenance (product-oriented service scape)	Maintenance contracts: involve (extended) warranty, spare parts and consumables delivery, inspection and diagnosis, updates/upgrades, cleaning/safe-keeping, and product installation/start-up/commissioning.	
		Advice (product-oriented service scape)	Advice contracts: through help desks, the provider dispenses information and assistance to customers regarding the management of product use, maintenance and repair (in case of self-repair) via phone, email, and internet services, allowing direct access to the supplier database.	
		Training (product-oriented service scape)	Training contracts: the provider offers training services to support the client while defining how to use a product and obtain best performance, improving the product efficiency during use while assuring the safety and/or improving the business.	
		Consultancy (product-oriented service scape)	Consultancy contracts: The provider offers consulting services to the customer regarding product development and use, as well as on business improvements.	
	Redistribution (slowing loop - additional use)	Donation	Free passing of goods from one consumer who does not use it anymore to another consumer who needs it.	Ertz et al. (2017c, p. 725); Ertz et al. (2017b, p. 4); Ertz et al. (2018); Cooper (2004); Cox et al. (2013)
		Swapping	Direct exchange of goods where no money or equivalent medium is involved. Goods may also be exchanged for services and services for goods.	
		Secondhand marketplace	Exchange between two parties involving the transfer of a pre-owned good in exchange for an amount of money considered equivalent to it.	
	Recovery (closing loop)	Product repair	Repair: A provider offers repair services that may be performed on- or off-site, directly or remotely, programmed or available 24/7 for emergencies. Preventive reparation: reparation programs that are defined by a contract may be proposed in standard, customised or special formats. Full reparation contract: A provider is completely responsible for the product performance. These solutions are nearly always provided through a package.	Gaiardelli et al. (2014, p. 513–515); Bakker et al., 2014a,b; Den Hollander et al. (2017)
		Remanufacturing/ refurbishing/ repackaging/ reconditioning	The provider remanufactures, refurbishes or reconditions existing products typically sourced from reverse logistics systems, inverse supply chain, take back schemes, trade-in programs, buy-back offers, or commercial returns. The provider offers a like-new product, often with a like-new warranty and a new serial number starting from an old product that has been completely or partially disassembled and rebuilt up to include all product updates.	Gaiardelli et al. (2014, p. 513–515); Bakker et al. (2014a); Den Hollander et al. (2017)

sampling procedure.

Second, we also used the managerial collaborative economy honeycomb 3.0, developed by Jeremiah Owyang, particularly its "goods" section as well as another managerial framework entitled "180 initiatives of the collaborative economy" from the Canadian review *Protégez-Vous*. All the cases and examples identified in these publications were retained in our sample as they were considered representative illustrations of PLE organizations. As such, we attempted to include in the sample as diverse organizations as we could so as to improve the external generalizability from this sample to the population of organizations engaging in PLE activities. The lack of selective choice of organizations, within the publications, prevented researcher bias (Johnson, 1997) and provided us a representative sample allowing for further generalisation (Flyvbjerg, 2006). As of 2 January 2018, we selected a sample of 150 organizations.

We collected relevant information on the BM of these organizations from publicly available sources, typically the organizational website. Past literature emphasized that such secondary data suffices to describe BMs (Teece, 2010). It also ensures descriptive validity and replicability (Tashakkori and Teddlie, 2002).

Table 3
Channels.

Channels	
Store	Physical facilities that concentrate distributed or collected products at a central hub, such as retailers' premises, plants, facilities, secondhand stores, donation centers.
Fixed touchpoints	Decentralized points of distribution or collection of products, such as decentralized fleets of cars or bikes, open libraries, or collection boxes.
Peers touchpoints	Individuals acting as decentralized points of distribution or collection of products.
Mail/transportation	Systems that enable the physical flow of products such as postal services, express delivery services, and more broadly transportation systems by land, air, or water.
Direct	Employees or providers in direct contact with the customers and the product for the performance of the product lifetime extension practice, such as sales personnel, technicians or consultants.
Digital interactive platform	Technological mediation such as a web platform or a mobile application, which provides information or live support on the extension of product lifetime.
Digital transactional platform	Technolgical mediation that provides the opportunity to conduct or schedule the exchange of the product whose lifetime is to be extended.

Table 4
Revenue model.

Revenue stream	
Asset sale	Exchanging the ownership of a product or service for money.
lending/renting/leasing	Temporarily granting the exclusive usage right of an asset.
licensing	Granting permission to use protected intellectual property, such as a patent in exchange for a fee.
Usage fee	Charged per use of a particular service.
Subscription fee	Charged for the use of the service.
Brokerage fee	Charged for an intermediate service.
Advertising	Charged for the display of advertisements.
Donation/crowdfunding	Money donated for no specific product or service in compensation.

3.4. Step 3: Coding process

The data was manually analysed and coded by two independent coders using the PLEBM framework (see Fig. 1). The first coder was one of the authors of this paper, but the second coder was not skilled in the relevant domain and not involved in the research at all. The features of the framework were clearly defined to both coders prior to coding to minimize coding errors (Cooper, 1988). The coding was binary for each feature (0 = no, 1 = yes). There were 4,500 coded terms, from which 81% were identical for both coders. The remaining 19% were settled through discussion by the two coders with another author of the paper acting as a judge to resolve any disagreement (Fastoso and Whitelock, 2010). The coding process provided binary feature vectors, which were then used for classification purposes.

3.5. Step 4: the cluster analysis

In keeping with the literature (Hartmann et al., 2016; Ketchen and Shook, 1996; Mooi and Sarstedt, 2011), a four-stage process built the PLEBM taxonomy: 1) selection of variables; 2) choice of dimension numbers; 3) choice of clustering algorithm and similarity measure; and; 4) validation and interpretation of the results. In this section, we present the first three stages. First, we selected the variables, i.e., dimensions and features, needed to determine affiliation to a specific group. The choice relied on two main considerations. The dimensions needed to be of high relevance (Milligan, 1996), and the number of dimensions chosen to conduct the cluster analyses was constrained by sample size (Mooi and Sarstedt, 2011). Hartmann et al. (2016) recommend a sample size of at least 2^m, where m refers to the number of clustering variables (see also Mooi and Sarstedt, 2011). Since our sample was composed of 150 organizations, seven dimensions seemed appropriate ($2^7 = 128$). As stated earlier, key activities and key partners were considered the most appropriate clustering variables. The remaining dimensions either lacked discriminatory power, in that most companies scored highly in one dimensional feature and less on the other (e.g., 88,7% as transactional), or were not addressing well our research questions to classify BMs according to their PLE. The five remaining dimensions of channels, customer segments, customer relationships, offering, and revenue streams, were used for descriptive purposes. Third, we used the *k*-medoïds clustering method and partitioning around medoïds (PAM) algorithm in *R* statistical package. A description of the PAM algorithm is provided in Appendix 1.

4. Results and discussion

This section refers to the fourth stage of the PLEBM taxonomy building, that is, the validation and the interpretation of the results.

4.1. Data sample analysis

The coding of the 150 companies revealed some key characteristics as shown in Table 5.

4.2. PLEBM cluster number

The number of clusters were determined by triangulating the results of different methods (Han et al., 2012; Mooi and Sarstedt, 2011) to balance the trade-off between parsimony and a reasonably large number of clusters to reflect divergences in the data (Hartmann et al., 2016). First, a rule of thumb suggests number of clusters equaling $\sqrt{\frac{n}{2}}$ (Han et al., 2012). With n = 150, eight would be an appropriate number, but seven could also potentially be retained as it implies more parsimony. Second, the elbow method was used with hierarchical clustering (Hartmann et al., 2016). The results suggested six as the most favourable number of clusters, but seven or eight were acceptable as well. Third, we used a statistical test called the Silhouette coefficient (Rousseeuw, 1987), which is more precise and reliable than a rule of thumb or the elbow method.

As shown in Table 6, the three coefficients are similar and very good, especially in a social science data context (Hambrick, 1984),

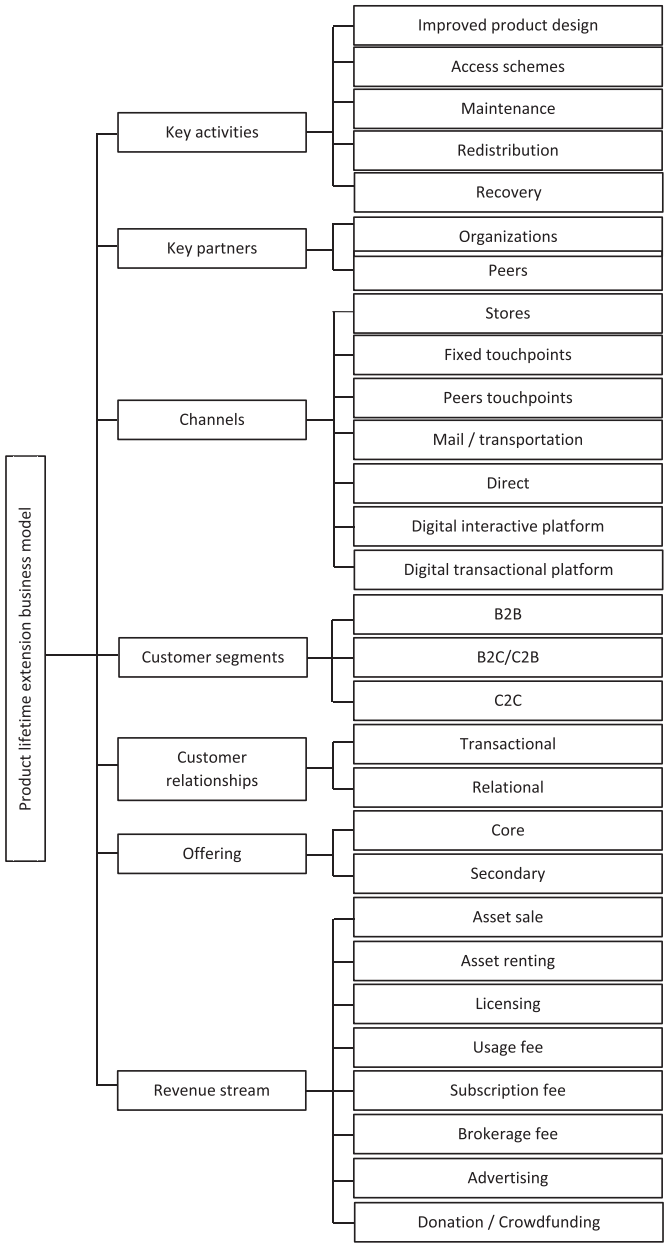

Fig. 1. The product lifetime extension business model (PLEBM) framework.

thus either the six-, seven- or eight-cluster configuration could be retained.

Subsequently, six-, seven- and eight-cluster configurations were run. The final number of clusters was validated through theoretical as well as practical meaningfulness and usefulness (Ketchen and Shook, 1996). The 6-cluster solution is less supported statistically and particularly conceptually since a design-focused cluster was missing which we thought to be an essential facet of PLEBM. The 8-factor solution, although showing better statistical support, lacked a compelling composition of clusters from a conceptual perspective. Some companies with markedly different BMs (e.g. Bixi and Amazon) were grouped together and a pattern of meaning was difficult to derive. The seven-cluster solution made the most sense from a conceptual viewpoint as the clusters demonstrated more intra-cluster homogeneity and inter-cluster heterogeneity. Thus, the seven-cluster solution was retained as it provided the most meaningful and compelling results from theoretical, practical and statistical perspectives.

4.3. PLEBM cluster results

The representative characteristics of the seven clusters are summarized in Table 7. The types are also displayed in a 5×2 matrix in Fig. 2.

As shown in Fig. 2, Business models under types A-C and E rely on products provided by other organizations, whereas type D rely on both organizations and peers, and types F-G rely on peers only. In terms of the key activities, three distinctive patterns are identified. Type C is the only one to conduct product design. Product design activities are furthermore coupled with maintenance and recovery activities. Types A and B engage both in maintenance and recovery, although type B's activities also stretch to access and redistribution systems. It is worth mentioning that types B and C have the lowest Silhouette coefficient, which is well reflected in the fact that they encompass a broader array of activities and are thus less clearly associated with a specific activity. In contrast, types E and F focus exclusively on access schemes, whereas types D and G are exclusively concerned with redistribution systems. It is also noteworthy that while most organizations rely on other organizations for the provision of products whose lifetime is to be extended, redistribution organizations tend to rely more heavily on peers.

The representative objects (medoïds) of the seven model types can be further described with the remaining five clustering dimensions, i.e. channels, customer segments, customer relationships, offering, and revenue stream. The results are shown in Table 8. Each of the seven clusters contained relatively uniform sets of organizations, to which specific labels (see also Fig. 2) were assigned based on their key characteristics as summarized in Table 7. A set of ANOVAs were run using the cluster variable as the factor and each of the 30 features as dependent variables. The results show that the clusters differ significantly on each of the features except on donation/crowdfunding in revenue stream. These results further demonstrate the robustness and validity of the proposed PLEBM framework (see last column in Table 8).

4.4. Discussion of the seven business models on product life extension

Type A: Relational product-as-a-service. Type A companies are mainly large corporate manufacturers. They create value by providing maintenance[2] and recovery, especially reparation (81.6%). Products are sourced by organizations (100.0%), but peers are also providers because these organizations are not only involved in B2B (81.60%) but also B2C/C2B configurations (50.0%). For example, *Samsung* or *Toshiba* provide repair and maintenance service to corporate clients but also to end users, i.e. consumers who may encounter issues with their smartphones, tablets or laptops. Consistent with their service orientation, a relatively high share of these organizations uses direct channels such as technicians and salespeople who intervene in client premises. Hence, the customer relationship is mainly relational (78.9%), and the high share of transactional relationships (68.4%) may be associated with the B2C segments, since large corporations lack direct contact with consumers as opposed to their business partners. For example, Cisco Certified Technicians work with the Technical Assistance Center to, quickly and efficiently, resolve support incidents at client sites. As such, the revenue stream consists mainly of usage fee (63.2%) with service agreements, and asset sales (55.3%).

[2] In the remainder, we use “maintenance” to refer to the “maintenance, advice, training and consulting” activity.

Table 5
Sample characteristics.

Dimensions	Sample proportions (n = 150)
Key activities	
Improved product design	14.0%
Access scheme	42.0%
Maintenance/advice/training/consulting	47.3%
Additional use (redistribution)	29.3%
Product repair	37.3%
Remanufacturing/refurbishing/reconditioning	21.3%
Key partners	
Organizations	79.3%
Peers	37.3%
Channels	
Stores	47.3%
Fixed touchpoints	6.7%
Peers touchpoints	19.3%
Mail/transportation	28.0%
Direct	35.3%
Digital platform – interactive	29.3%
Digital platform – transactional	50.7%
Customer segments	
B2B	43.3%
B2C/C2B	60.0%
C2C	21.3%
Customer relationships	
Transactional	88.7%
Relational	39.3%
Offering	
Core	58.7%
Secondary	41.3%
Revenue stream	
Asset sale	45.3%
Lending/renting/leasing	30.0%
Licensing	10.0%
Usage fee	44.7%
Subscription fee	32.7%
Brokerage fee	16.7%
Advertising	4.0%
Donation/Crowdfunding	6.0%

Table 6
Silhouette coefficients.

Number of clusters	Silhouette Coefficient
6	0.631
7	0.651
8	0.681

Note: the closer the coefficient is to 1.000, the better (Kaufman and Rousseeuw, 1990).

Type B: Brick & click product nurturer. Type B organizations conduct virtually all types of PLE activities, except product design. They specialize in both maintenance (100.0%) and recovery (100.0%), while redistribution (76.5%), access (64.7%), and remanufacturing (58.8%) activities are less systematic. In addition to the organization-provided products, some companies also rely on peers to source products. Many car (e.g. *Mercedes-Benz*, *BMW*, *Audi*, *VW*, *Toyota*, *Volvo*, *Renault-Nissan*) or truck/engine (*Iveco*, *Komatsu*, *Caterpillar*, *Scania*) manufacturers are included in this group. For example, *Mercedes-Benz* offers access solutions particularly for electric, hybrid or other new product introductions (Gaiardelli et al., 2014). Through its franchisees, cars can be traded-in (redistributed) and resold after refurbishing. The company also provides an express service for car maintenance and repair. The scope of the different maintenance services varies from tracking of repair activities (*Iveco*), recommendation of optimum machines, options and attachments (*Komatsu*), consumables and spare parts delivery (*Volvo*, *Volkswagen*), to client information concerning the nearest service center in case of failure (*Audi*, *BMW*). In contrast to type A organizations, Type B ones offer redistribution and access

Table 7
PLEBM cluster results with respective medoïds, size, and Silhouette coefficients.

Cluster (type)	Key partners		Key activities					Size	Silhouette coefficients
	Organizations	Peers	Improved product design	Access scheme	Maintenance/advice/consulting	Redistribution	Recovery and repair		
Cluster 1 (A)	1	0	0	0	1	0	1	38	0.717
Cluster 2 (B)	1	0	0	1	1	1	1	17	0.267
Cluster 3 (C)	1	0	1	0	1	0	1	18	0.268
Cluster 4 (D)	1	1	0	0	0	1	0	13	0.502
Cluster 5 (E)	1	0	0	1	0	0	0	32	0.823
Cluster 6 (F)	0	1	0	1	0	0	0	19	0.803
Cluster 7 (G)	0	1	0	0	0	1	0	13	1.000

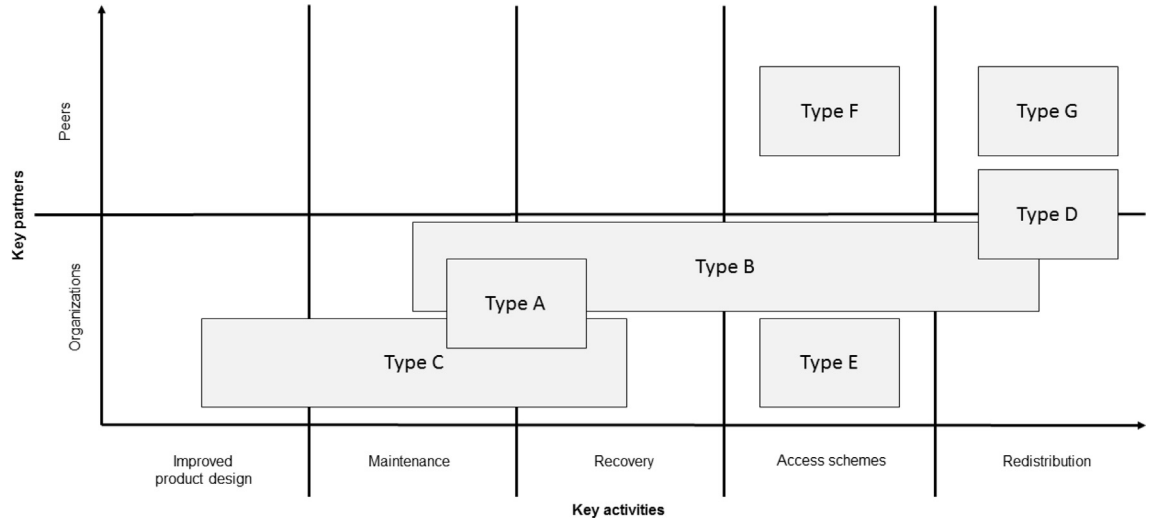

Fig. 2. Product lifetime extension business model (PLEBM) matrix.
Type A: Relational product-as-a-service (Samsung, Toshiba) Type B: Brick & digital product nurturer (Toyota, Caterpillar) Type C: Quality product designer (Mont-Blanc, Louis Vuitton) Type D: Secondhand vendor (The Salvation Army, eBay) Type E: Marketer-managed access system (Bixi, Car2Go) Type F: Peer-to-peer access broker (Turo, Sharetribe) Type G: Consumer redistribution marketplace (Craigslist, Kijiji) Type G: Consumer redistribution marketplace

opportunities, spanning more comprehensively the continuum of product nurturing activities. For example, *AgitoMedical*, in addition to offering a variety of maintenance service options, also re-commerces used medical equipment and spare parts (i.e., redistribution), as well as refurbished equipment (i.e., refurbishing), sourced from trade-in schemes (i.e., redistribution). In addition, *Agito* offers mobile rental solutions (i.e., access) to its clients (Krarup et al., 2015). Hence, the revenue model is more diversified, namely with asset sale as well as lending/renting/leasing, and licensing, in addition to usage fee. Although mostly using physical stores (i.e., bricks) and direct channels, these organizations also rely heavily on digital platforms (i.e. click), but in interactive rather than transactional form.

Type C: Quality product designer. Type C companies uniquely focus on product superior design (100%), or product "nature" rather than "nurture". Some also perform maintenance (72.2%), and recovery in the form of reparation (55.6%). Hence, together with Type B companies, they span across a broad array of activities. However, in contrast to Brick-and-click product nurturers specializing on PLE activities improving the nurture of products (i.e., maintenance and recovery), quality product designer focus on activities improving the nature of products. They can be roughly divided into two groups: organizations that manufacture high-end luxury (e.g. *Louis Vuitton*, *Mont-Blanc*, *Rolex*); and organizations that produce mass consumption goods with superior product design (e.g. *Apple*, *Lego*, or *Patagonia*). They focus on superior design while offering repair and recovery solutions. *Apple* established the Apple Repair Center for repair and the Official Apple Support for advice and consultancy (i.e. maintenance). Thus, stores, as well as transactional platforms and mail/transport, constitute predominant channels of product sourcing. As some of these organizations generate revenues through usage fee (76.5%), typically through maintenance contracts, a higher share relies on asset sale (82.4%).

Type D: Secondhand vendor. Type D organizations create value through redistribution only. The products are sourced by organizations and by peers. For example, *Amazon*, *eBay*, *The Salvation Army* or *Ikea* facilitate the return or exchange of pre-owned products from peers. *Amazon*'s used books section enables anyone to resell pre-owned books to others. The Fulfillment By Amazon (FBA) service enables peers to more easily and efficiently buy and resell pre-owned books while *Amazon* manages the logistical aspects related to the exchange. Although the organizations in this cluster have an exclusively transactional orientation, their channels vary from stores to transactional platforms, including mail/transportation. The type of revenue stream ranges from asset sale (the vast majority) to brokerage fee (30.8%) while other streams are more marginal. *The Salvation Army* or *Ikea*, for example, mostly rely on asset sale, while *eBay* takes brokerage fees for each exchange conducted on the transactional platform.

Type E: Marketer-managed access system. Organizations in this cluster, such as *Car2Go*, *Getable*, or *Vélib'*, create value by providing access to needed products through digital platforms of the transactional type (75.0%), and to a lesser extent stores (34.4%) or fixed touchpoints (31.3%). This cluster can be labelled marketer-managed access system as it comprises organizations, which lend, rent or lease their assets without allowing peers to source products by themselves or exchange with each other (i.e., C2C). This cluster conflates with access-based consumption (e.g. Zipcar) (Bardhi and Eckhardt, 2012) or marketer-managed sharing systems (e.g. Bixi) (Lamberton and Rose, 2012). Popularly misquoted as *sharing* systems, as underscored by several authors (Murillo et al., 2017; Schor, 2016), the clustering confirms that the sharing denomination is misleading. Subscription fees (71.9%) prevail, while lending/renting/leasing (68.8%) follows closely.

Type F: Peer-to-peer access broker. In contrast to type E, type F organizations consist of mostly digital transactional platforms (88.9%) allowing peers (100.0%) rather than organizations (5.6%) to source products, in mostly C2C exchange configurations (34.4%). For example, *Drivy* or *Turo* are both peer-to-peer car rental platforms; *Boatsetter* is a C2C boat rental site; while p2p rental websites *Sharetribe* or *Peerby* stretch across a wider range of product categories. Corresponding revenue models are predominantly brokerage fee (88.9%). These organizations position themselves as PLE champions since their PLE activities are core (100.0%) to their BM.

Type G: Consumer redistribution marketplace. Type G is similar to type D, in that organizations focus on redistribution only (100.0%). However, like type F, type G rely exclusively on peers (100.0%) for product sourcing. Exchange configurations involve most frequently peers only (78.6%), but also B2C/C2B exchanges (42.9%).

Table 8
PLEBM clusters general statistics.

PLEBM dimensions			A Relational product-as-a-service	B Brick & click product nurturer	C Quality product designer	D Second hand vendor	E Marketer-managed access system	F Peer-to-peer access broker	G Consumer redistribution marketplace	F statistic[a] and level of significance
Share of companies (as percentage of total sample)			25,30%	11,30%	12,00%	8,70%	21,30%	12,00%	9,30%	
Key activities	Improved product design		---	---	100,00%	7,70%	3,10%	5,60%	---	127.926***
	Prolonged use	Access scheme	---	64,70%	---	7,70%	100,00%	100,00%	7,10%	128.045***
		Maintenance / advice / training / consulting	100,00%	100,00%	72,20%	7,70%	6,30%	---	---	115.218***
	Additional use (redistribution)		---	76,50%	5,60%	100,00%	9,40%	---	100,00%	86.410***
	Recovery (reintegration)		81,60%	100,00%	55,60%	---	---	---	---	59.656***
		Product repair	81,60%	94,10%	50,00%	--	---	---	---	51.168***
		Remanufacturing / refurbishing / reconditioning	42,10%	58,80%	33,30%	---	---	---	---	10.685***
Key partners	Organizations		100,00%	100,00%	100,00%	100,00%	100,00%	5,60%	---	596.787***
	Peers		13,20%	29,40%	16,70%	84,60%	---	100,00%	100,00%	45.497***
Channels	Stores		50,00%	100,00%	72,20%	61,50%	34,40%	11,10%	7,10%	10.295***
	Fixed touchpoints		---	---	---	---	31,30%	---	---	8.522***
	Peers touchpoints		---	---	---	---	12,50%	83,30%	71,40%	39.115***
	Mail / transport		26,30%	5,90%	50,00%	38,50%	21,90%	5,60%	64,30%	4.415***
	Direct		73,70%	82,40%	38,90%	15,40%	6,30%	---	---	22.358***
	Digital platform	Interactive	36,80%	64,70%	27,80%	7,70%	15,60%	11,10%	42,90%	3.939**
		Transactional	21,10%	11,80%	61,10%	53,80%	75,00%	88,90%	57,10%	9.515***
Customer segments	B2B		81,60%	52,90%	55,60%	23,10%	31,30%	5,60%	7,10%	10.666***
	B2C/C2B		50,00%	64,70%	77,80%	84,60%	84,40%	11,10%	42,90%	7.241***
	C2C		---	---	5,60%	23,10%	---	94,40%	78,60%	67.712***
Customer relations	Transactional		68,40%	82,40%	88,90%	100,00%	100,00%	100,00%	100,00%	5.001***
	Relational		78,90%	70,60%	72,20%	---	12,50%	---	---	26.477***
Offering	Core		13,20%	17,60%	44,40%	69,20%	96,90%	100,00%	100,00%	33.979***
	Secondary		86,80%	82,40%	55,60%	30,80%	3,10%	---	---	33.979***
Revenue stream	Asset sale		55,30%	82,40%	83,30%	92,30%	9,40%	---	21,40%	19.672***
	Lending/renting/leasing		7,90%	70,60%	11,10%	7,70%	68,80%	22,20%	7,10%	13.877***
	Licensing		15,80%	52,90%	---	---	---	---	---	10.808***
	Usage fee		63,20%	76,50%	77,80%	15,40%	28,10%	---	35,70%	9.652***
	Subscription fee		26,30%	35,30%	22,20%	7,70%	71,90%	11,10%	21,40%	6.541***
	Brokerage fee		---	---	---	30,80%	3,10%	88,90%	28,60%	35.468***
	Donation / crowdfunding		---	5,90%	---	7,70%	6,30%	5,60%	7,10%	0.627 (n.s.)
	Advertising		---	---	5,60%	7,70%	3,10%	---	42,90%	8.351***

Note: The proportions pertaining to the key activities, key partners, channels, customer segments, customer relations, and revenue stream may add up to more than 100% since companies may engage in multiple PLE activities, use both organizations and peers as partners, use multiple channels, work with multiple consumer segments, operate both transactionally and relationally, and generate multiple revenue streams. However, the offering variable cannot add up to more than 100% since PLE activities cannot be simultaneously secondary and core to the organization.
Note: [a] F statistic based on df1 = 6 and df2 = 143.
* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$.

Accordingly, peers touchpoints (71.4%) or mail/transport (64.3%) channels prevail. Again, the web appears as a powerful enabler for peer-powered exchanges since both transactional (57.1%) and interactive (42.9%) channels are used. For example, *Kijiji* or *Craigslist* websites allow the posting, visualization, advanced search and drill-down capabilities of pre-owned products. However, the website does not support online transaction. Actual transactions are conducted offline with peers (i.e., peers touchpoints). Although no specific revenue model seems to stand out in this cluster, it is worth noting that advertising revenues are at their highest level (42.9%) in this cluster.

5. Discussion

5.1. Theoretical implications

The main output of this research is the development of a systematic, integrative, inductively-derived taxonomy of BMs, called

the product lifetime extension BMs (PLEBM). In advancing this body of academic knowledge, this study encompasses the roles of both organizations and consumers as important PLE enablers. The resultant taxonomy of organizations contributes to the academic literature in PLE, CE and BMs. Our systematic integration of the full-spectrum of PLE practices and BM, as well as, the links explored in the PLEBM framework are unique. These aspects integrate various concepts that have been studied separately in past research. Specifically, the PLEBM framework developed in this study integrates the nature and nurture strategies of PLE (Cox et al., 2013) and the BM canvas (Osterwalder and Pigneur, 2010) and provides insights into the state-of-the-art in PLE operationalization. As such, this study provides several theoretical implications to the field of the circular economy in general, and PLE, in particular.

First, the proposed typology is unique in several regards. Although past typologies classifying circular or sustainable business models inevitably encompassed various forms of PLE, few endeavoured classifying PLEBM exclusively. Furthermore, PLE-focused typologies considered only specific forms of PLE such as product-service offerings or product design or reuse, among many others, so that a holistic or an integrative framework of existing PLE initiatives was lacking in the literature.

The absence of a holistic perspective on PLE, which integrate both nature strategies (i.e., improved product design) and nurture ones (i.e., product lifetime prolonging), is partly responsible from the current emphasis on planned obsolescence (e.g., PLATE Conference 2017). Rather than focusing on what does not work (i.e., planned obsolescence), this study adopts a positive science perspective (White, 1992) and instead focuses on what works (i.e., PLE strategies) and how it may be developed even further. This study's taxonomy spans a large spectrum of PLE strategies by integrating both design efforts (i.e., nature strategies) (Bakker et al., 2014a) and product conservation and recovery strategies (i.e., nurture strategies) (Bakker et al., 2014a; Cox et al., 2013).

Second, in contrast to other typologies, which are managerially-grounded (e.g., Den Hollander et al., 2017; Nussholz, 2017a, 2017b; Whalen et al., 2018), our classification offers unique insight into the (pro)active role of consumers (in addition to organizations) to extend product lifetimes. A key finding in this regard is that, consumers' input lies mainly in access and redistribution schemes, whereas the bulk of PLE activities, consisting of design, maintenance and recovery falls predominantly under corporate realm. With the rise of artificial intelligence, Big Data, machine learning, intelligent devices and communication technology, consumer input could be envisioned for these three PLE activities as well. For example, 3D printing could provide spare parts or components to consumers design (nature strategies) but also repair, upgrade, remanufacture/rebuild/recondition like new or refurbish products (nurture strategies) (Despeisse et al., 2017). Trace and returns systems could optimize redistribution (Accenture, 2014) through consumer return, trade-in, buy-back processes, which are essential to inverse logistics and supply chains. Therefore, this study contributes to both PLE and the circular economy by emphasizing the overlooked role of both organizations and consumers in PLE, as alluded to in past consumer behavior literature (e.g. Cooper, 2004; Ertz et al., 2017c), and the importance of IT in enhancing that role even further (e.g. Accenture, 2014; Jabbour et al., 2017).

Third, brick and digital product nurturers (type B), quality product designers (type C), and relational product-as-a-service (type A) business types are particularly interesting as they span across several PLE activities, while involving consumers to some extent. These types of businesses seem to espouse the notion of circularity most comprehensively. However, they happen to be mostly larger-sized multinationals, which suggests that furthering organizational involvement in PLE requires capacity and resources.

Fourth, arguably, one of the most interesting findings is that, despite the numerous calls made in the literature for additional integration of improved product design to extend product lifetimes (e.g., Bakker et al., 2014a, 2014b; Den Hollander et al., 2017), improvement of the product design is not a privileged PLE orientation. This lack of focus on long-life design could support the planned obsolescence theory (Cooper, 2004; Pope, 2017; Rivera and Lallmahomed, 2016). Indeed, apart from some niche organizations characterized by particular positionings such as upper-scale, luxury or superior design, most companies favor product nurture instead of product nature strategies. This nurturing takes mainly the form of prolonged use (i.e., maintenance and access), recovery (i.e., repair and remanufacturing), and additional use (i.e., redistribution). All these activities are arguably very beneficial from a financial perspective as they cut costs (e.g. remanufacturing diminishes the purchase of new supplies) and generate a continuous income after sale (e.g. maintenance services, leasing services, recommerce). In contrast, nature strategies supporting long-life product design may be less attractive financially as per the planned obsolescence argument. Quality product designers combine product design with maintenance and recovery activities in order to complement revenues from asset sale with usage/subscription fee. It appears that organizations tend to implement PLE to ensure economic sustainability but not necessarily environmental sustainability. Our findings are consistent with previous literature in that "the main aim of the circular economy is considered to be economic prosperity, followed by environmental quality" (Kirchherr et al., 2017, p. 221). Similarly, PLE activities seem deployed to ensure economic sustainability beyond environmental or social sustainability.

Finally, past literature predominantly used qualitative methods to derive taxonomies (e.g., Gaiardelli et al., 2014; Whalen, 2017). In line with the importance of adopting quantitative approaches to taxonomical endeavours (Hartmann et al., 2016), the quantitative approach of this study ensures broader generalizability and representativeness. Besides, this study offers a nuancing of the theory of planned obsolescence and reduced product lifetime by exploring different ways to manage PL as well as the central role played by both organizations and consumers in this process.

5.2. Managerial implications

Managers seeking to develop and maintain circular organizations could benefit from this study. While PLE strategies have been widely but disparately reported in the CE literature, the PLEBM framework and generic taxonomy offered in this study provides a comprehensive and systematic overview of PLE and its various configurations in practice from a business-oriented vantage point. The proposed classification enables managers to position their own organization in its competitive landscape to gauge whether their organization enjoys a substantial "circular advantage" (Accenture, 2014). The framework and taxonomy further facilitate the recognition of potential gaps in the market. One of such is clearly the lack of focus on improved product design from organizations. Another could be engaging peers more intensively since as for now, organizations remain the most important pre-owned product suppliers, whereas consumers intervene only in redistribution and access schemes. Big data, artificial intelligence, 3D printing, and internet of things may provide further opportunities for better connecting with peers and allowing them to engage more actively in other key PLE activities.

5.3. Implications for government and industrial policy

PLE and BMs have far-reaching societal impacts. When framed

in the broader concepts of the circular economy, PLE relates to sustainability, whereas BMs operate under a profit-making logic. Government and industrial policy makers have a critical role in integrating their respective positions. The necessary infrastructure needed for many of the potential developments in the PLE-BM nexus, such as consumer involvement in design, maintenance and recovery, or corporate design, require leadership and efforts from government agencies and industrial professional groups, as well as cross-sectoral cooperation and citizen approval, for setting standards and nation-wide innovations (e.g. 3D printing, Internet of things, FabLabs). The proposed PLEBM framework and taxonomy is a primer to develop policies and identify weak infrastructure areas relevant for sector- or nation-specific strategy to build competitiveness.

$$\text{dist} = \|x - y\|_2 = \sqrt{(x_1 - y_1) \times (x_1 - y_1) + \ldots + (x_n - y_n) \times (x_n - y_n)} = \sqrt{b + c}$$

5.4. Research limitations and avenues for future research

The PLEBM framework and taxonomy serve as foundation for advancing research in the emergent field of PLE and call for avenues for future research. First, the taxonomy has been developed on two out of seven dimensions of the PLEBM to facilitate understanding. Nonetheless, more than two dimensions could be used to develop more complex classifications. Second, taxonomies are dynamic and changing (Hartmann et al., 2016). Therefore, longitudinal case studies may help determine whether and to what extent some organizations move from one type of PLEBM to another. Third, comparison analyses may further shed light on the comparative financial, managerial or marketing performance of various types of PLE BMs. Fourth, although the findings are robust for a study conducted in a social sciences context, use of larger and richer samples or focus on specific industries, may improve robustness of findings even further.

Compliance with ethical standards

Conflict of interest

The authors declare that they do not have any conflict of interest.

Ethical approval

This study does not contain any studies with human participants performed by any of the authors.

Appendix 1. The PAM algorithm

The *k*-medoïds algorithm groups n objects into *k* clusters by minimising the sum of dissimilarity between each object, *p*, and its corresponding representative object, o_i (medoïd), for all objects in cluster C_i (Hartmann et al., 2016, p. 1391). The corresponding formula reads as follows:

$$\text{Min E} = \sum_{i=1}^{k} \sum_{p \in c_i} dist(p, o_i$$

In line with previous classification studies (e.g. Hartmann et al., 2016), the *k*-medoids algorithm was deemed preferable over *k*-means algorithm, because the medoids which are the cluster representatives consist of observed BMs from the sample, which makes the results more meaningful. Han et al. (2012) also emphasized that the *k*-medoid algorithm is less sensitive to outliers.

Since our similarity measure is binary, one important issue is whether negative matches (i.e. neither BM having a particular feature) is relevant to determining their similarity (Everitt et al., 2011). In this study, we posited that the co-absence of features was relevant for the similarity of two BMs. The Euclidean distance measure was used, which includes both negative and positive matches. In fact, this measure determines the distance only on the basis of mismatches b and c (Choi et al., 2010):

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