

A Design for X framework for PSS business models

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Abstract: Manufacturing companies are moving from product-centric offerings to services and solutions in order to increase revenues and build sustainable competitive advantage. This strategy is generally achieved through the provision of a product–service system (PSS) that may be considered as the combination of tangible products with a series of related intangible services in order to meet specific customer needs’. Therefore, the material products need to be characterized by specific design features in order to make more efficient and effective the provision of the product-related services. Moreover, the adoption of a product-service-system (PSS) business model necessitates an accurate attention on all the phases of the product life-cycle. According to this line of thought, concurrent engineering approach and, in particular, the adoption of design-for-x (DfX) techniques can represent an effective instrument to decrease maintenance cost, facilitate reuse and extent product life-cycle in order to effectively provide a PSS. The literature acknowledges the likely impacts of DfX approach in the implementation of PSS. However, the relationships between DfX types with the different PSS types as well as the DfX operational levers that manufacturing companies can implement based on the envisaged DfX type adopted still remain largely an uncharted territory. In order to fill this gap, this paper proposes a new literature-based DfX typology encompassing the suitable DfX types to be considered when implementing a PSS business model. The evaluation of the potential impacts of each DfX type on different configurations of PSS business models has been also investigated. This paper also presents a toolkit aimed at helping practitioners at identifying and evaluating practical actions to be taken in order to improve the product design according to the configuration of the envisaged PSS business model (BM) configuration.

Keywords: Concurrent engineering; Design-for-X; Servitization; PSS business model;

1. Introduction

In recent years, manufacturers are under considerable pressures. Since the pressures in focusing on more heterogeneous customer needs have increased more and more, many companies have started to introduce new methods and techniques to support the product design phase (Huang, 1996; Abdalla, 1999). In particular, as new product-service systems (PSS) business models can represent for manufacturing companies a new way to achieve advantages and profits (Neely, 2009), the adoption of concurrent engineering techniques in designing a product is nowadays very critical since it has to consider different aspects of the product life-cycle. The adoption of a PSS business model necessitates an accurate attention on all the phases of the product life-cycle (Baines et al. 2007). According to this line of thought, concurrent engineering approach and, in particular, the adoption of design-for-x (DfX) techniques are presented by the literature as an effective instrument to decrease maintenance cost, facilitate reuse and extent product life-cycle (Goffin, 2000; Gaiardelli, Cavalieri and Saccani, 2008; Holt and Barnes, 2009). Despite this acknowledged importance, how the DfX approach can represent an effective lever to implement the different types PSS business models (Tukker, 2004; Adrodegari et al., 2015) is an under-investigated topic. Thus, in order to fill this gap, this paper proposes a new literature-based DfX typology encompassing the suitable DfX types to be considered when implementing a PSS business model. The evaluation of the potential impacts of each DfX type on different

configurations of PSS business models has been also investigated. This paper also presents a toolkit aimed at helping practitioners at identifying and evaluating practical actions to be taken in order to improve the product design according to the configuration of the envisaged PSS business model (BM) configuration. The paper is structured as follows: section 2 provides the research setting dealing with the relationships between DfX techniques and PSS business models. Section 3 shows the objectives and methodology adopted in this paper with focus on the 2-level DfX framework developed by the authors. The 2 levels of the DfX framework is explained in details in sections 4 and 5 with the presentation of the main findings while conclusive remarks and directions for future research are drawn in section 6.

2. Research setting

2.1 Design for X as a technique to implement concurrent engineering

The pressures in improving market targeting, focusing on customer needs and reducing the time-to-market have increased more and more in recent years. Concurrent engineering (CE) has emerged as the solution to the problem of achieving more rapid and effective product innovation processes (Badham, Couchman and Zanko, 2000). In conventional design product process, each phase (e.g. concept exploration, product design, testing, etc.) is generally controlled by just one company function at a time (e.g., marketing, engineering, manufacturing). Conversely, CE is a systematic approach that consider all

the elements of the product life-cycle from conception through disposal, including quality, cost, schedule and user requirements (Creese and Moore, 1990). As in the current competitive environment companies have to deliver more and more high-quality products (Tan et al. 2010), CE can therefore represent a way to gain new advantage and reduce cost. However, changing from a sequential design organization to a concurrent organization, is always problematic since it needs the involvement of all the functions in the company during the design phase (Lettice, Smart and Evans, 1995). Moreover, the typical objectives of CE such as optimizing product quality, minimizing manufacturing cost and shortening delivery time are often too abstract with no presence of concrete guidelines and methodologies to achieve the results hoped for (Malinowski and Nowak, 2007). Design for X (DfX) deals with a design approach that helps reaching the objectives typical of CE because it concerns practical design guidelines, tools and/or metrics to focus on a specific stage in product life-cycle (e.g. manufacture, assembly, etc.), or a specific product virtue (e.g. quality, environmental impact, etc.) (Holt and Barnes, 2009). One of the first contributions on DfX in the literature was that of Boothroyd and Dewhurst (1983) who started to analyse assembly constraints during the design phase leading to the emergence of the first DfX type, namely Design for assembly (DfA). As a generalization of DfA, Stoll (1988) developed the concept of Design for manufacturing (DfM). Afterwards, researchers started to focus also on other life-cycle phases with the development of other DfX techniques: Design for environment (Fiksel and Fiksel, 1996), Design for recyclability (Henstock, 1988) and Design for life-cycle (Bras and Emblemståg, 1995) with few contributions also on the middle-of-life (MOL) product phases allowing the creation of Design for criteria like Design for supportability (Goffin, 2000) and Design for maintainability and serviceability (Desai and Mital, 2006).

2.2 The role of DfX in PSS business models

In the current global economy, manufacturers can no longer rely on the traditional product-focused business models with competitive dimensions such as time, cost, quality, flexibility or environment (Dimache and Roche, 2013). The increasingly competitive intensity made product-based competitive advantage difficult to maintain. It is common agreement in literature that extending the service business through what has been defined as servitization can lead to generate new, less imitable, competitive advantages and new additional revenues and profits (Oliva and Kallenberg, 2003; Brax, 2005; Neely, 2008; Baines et al., 2009). For these reasons, companies are reorienting their value propositions from selling products to provide product-service systems (PSS). Evidences show that to be successful in this transformation, a company should not only adapt its proposition, but also needs to redesign its business model (Baines et al., 2009; Kindström, 2010; Adrodegari and Saccani, 2017). Designing a product using a “service vision” is a critical activity for successfully implement a PSS business model: several preferable product properties such as the ability to be maintained, upgraded, and reused

easily, can be identified in order to increase the value creation and sustain specific types of PSS (Tukker, 2004). Adopting the PSS BM classification provided by Adrodegari et al. (2015), in product-oriented business model (BM), the design of products is mainly focused on the satisfaction of customer technical requirements (Table 1).

Table 1: PSS Business model types (adapted from Adrodegari et al. 2015)

PSS BM Type	Description
Product focused BM	The provider sells the product or the system and separately it sells services customer needs during the use phase of the product (e.g. break-fix repair, maintenance contract).
Product and processes focused BM	The company offers services, both in the pre- and after-sale phases that aim to optimize customer processes.
Access focused BM	The customer does not buy the product but pays a fixed regular fee to gain access to it. The fee is not related to the product actual usage and may include additional services (e.g. maintenance and assurance costs).
Use/Outcome focused BM	The customer does not buy the product or system but pays a variable fee that depends on the usage of the product (pay-per-usage time, pay-per-usage unit) or the achievement of a contractually set result in terms of product/system performance or outcome.

In a PSS BM, the design of the product becomes critical. In fact, even though the physical product is considered no more to be at the core of the offering as they emphasize the usage or the outcomes of the product, it has to be developed carefully with appropriate features and functions in order to deliver advanced services (Kim et al. 2010). Therefore, CE approach and, in particular, the adoption of DfX techniques could be an effective instrument. The literature has investigated how the DfX approach can be exploited in order to improve some product features useful to effectively provide single product-related services such as serviceability (Gaiardelli, Cavalieri and Saccani, 2008, Tan et al. 2010) or supportability (Goffin, 2000). Moreover, a life-cycle perspective can be used in order to evaluate the potential benefits in the provision of a PSS offering from the adoption of Design for X approach (Sundin, 2009; Sassanelli et al. 2016). However, the specific impacts of DfX options and techniques on different PSS business model configurations is a not-covered topic in the literature. Moreover, the literature also lacks the investigation about managerial tools helping companies in the choice of the appropriate DfX techniques and operational levers to be adopted in order to sustain a specific type of PSS business model.

3. Objectives and methodology

Given the context described in previous sections, the objectives of this paper are twofold, namely:

1) a literature systematization about the DfX methodology in order to develop a structured DfX typology with the

evaluation of the potential impacts of each DfX type on different configurations of PSS business models;

2) the development of a toolkit aimed at helping practitioners at identifying and evaluating practical actions to be taken in order to improve the product design according to the configuration of the envisaged PSS BM configuration.

In order to achieve the two objectives, a 2-level DfX framework has been developed by the authors (Figure 1). In order to develop the Design for X framework, a literature analysis has been carried out according to a structured keyword search performed in the Scopus® database using queries obtained from the combination of two sets of keywords. The first set included keywords related with PSS research stream (e.g. Product-service system; Servitization, etc.) while the second set included keywords related with Design for X research stream (e.g. DfX, Design for X, Design for Serviceability, etc.).

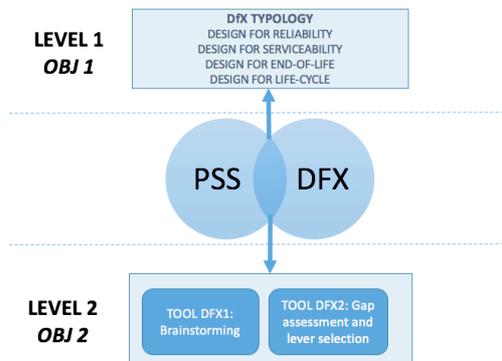


Figure 1: Design for X framework

According to the results of the literature analysis, the two level of the framework have been developed. The first level of the framework concerns a structured DfX Typology encompassing all the likely DfX types to be considered when moving to PSS business models. Moreover, the impacts and the likely benefits of each DfX type has been investigated depending on the envisaged PSS type. Considering the plethora of different options evaluated in the literature concerning Design for X, four specific product features have been identified as the most suitable to be focused on in order to implement a PSS business model, namely: Reliability (DfR), Serviceability (DfS), End-of-life (DfEoL) and Life-cycle (DfLC). Indeed, since the literature investigates a huge number of x-abilities, some of them have been included in one of the four types identified in the presented DfX Typology. The second level, DfX process model, provides a common practical approach for companies to correctly adopt the Design for X approach during design phase. The aim is to guide companies in identifying the most suitable design levers to be adopted for a PSS business model. Indeed, specific managerial practical actions have been identified for successfully adopting one or more of the 4 DfX options selected. Therefore, the DfX framework aims at helping companies to choose the appropriate product features (life phase and/or virtues) to be enhanced and the levers to be adopted depending on the new envisaged business model configuration.

4. LEVEL 1: The DfX typology

In line with the description of the framework presented in the previous section, Table 2 shows the DfX typology emerged by the literature analysis carried out by the authors with the impact level for each PSS BM type. For each DfX type, next section provides a definition, how it is possible to implement that and some potential impacts for PSS business models.

Table 2: Impacts of DfX types on PSS BM types (L – Low, M – Medium, H – High)

BM TYPE	Reliability	Serviceability	EOL	Life-Cycle
Product	M	M	L	L
Product and processes	M	H	L	L
Access	M	M	H	M
Use/Outcome	H	H	M	H

4.1 Design for reliability

Reliability can be defined as "the probability of a product performing without failure a specified function under given conditions for a given period of time" (Kuo, Huang and Zhang, 2001). Reliability is strongly related to maintenance particularly where the manufacturer is responsible for maintaining the product or also when warranties are set (Holt and Barnes, 2009). Therefore, this is an important feature to be considered when the manufacturer is responsible for the maintenance of the physical product. Considering reliability product during the design phase concerns important trade-off analysis. In fact, on the one hand, testing the reliability level of a product during design phase, involves methods which extend the time to market. On the other hand, a low level of reliability design leads to potential failures of the product causing warranty claims and dissatisfied customers. Usually, Design for reliability is the only technique adopted in product focused business model, as it is important to reduce warranty costs. In fact, in this BM configuration, the design of products is mainly focused on the satisfaction of customer technical requirements and the manufacturer is not interested in long-term durability and product life-cycle. Design for reliability is also suggested for the other PSS BM types since it helps in reducing maintenance actions and extending the product life-cycle.

4.2 Design for serviceability

Companies that adopt a PSS business model often provide their products with combined services such as installation, remote monitoring, maintenance contracts and spare parts provision. For this reason, products need to be easily serviced in order to increase efficiency in service provision and boost profitability (Barkai, 2005). This usually represents some criticalities, since the complexity of equipment has increased a lot in recent years (Goffin, 2000). Moreover, services can be a very profitable area with margins that could exceed those made

thanks to the only product selling (Knecht, Leszinski and Weber, 1993). Design for serviceability (DfS) involves a design approach that considers and measures the ease with which a system can be serviced, how often it needs servicing and how easy it is to service (Cavaliere, Gaiardelli and Saccani, 2008). Therefore, the term serviceability will refer to all the services that could be provided attached to the product and not only maintenance and repair. Also inspectability issues are comprised in the definition of serviceability. This DfX type may be very effective for product and processes focused BM type since design of products is mainly focused on the satisfaction of customer technical requirements and on enabling the provision of the service portfolio associated to the product. Moreover, this DfX type is strongly suggested in case of sales of maintenance contracts and in all the BM configurations where the manufacturer is responsible to assure a high level of product uptime.

4.3 Design for end-of-life

The disposal phase and all the activities concerning product End-of-Life (EoL) have become very important to be considered in a product. Moreover, among all life-cycle stages of a product, design and development stages are the ones that most influences the later stages in terms of environmental impacts. In order to achieve sustainable product development, one of the considerations to be taken during the design stage is EoL management. When a product reaches the end of its life, some components may be re-used on other products. This could be a very effective strategy for example in access focused business models where the customer does not own the product but it only pays for accessing the product. The focus on end-of-life management phase might address a company to have a high percentage of elements that can be re-used after the products' useful life (strategically for rental or leasing). In this paper Design for End-of-Life is seen as an approach that gathers two other DfX options: Design for recycle and Design for disassembly. In recent years recycling materials has become a very important issue since the quantity of used products being discarded is increasing dramatically. The opportunity of recycling products or also single components is very important for PSS business models, in particular in those cases in which it is important to re-use parts after the end of product life-cycle. In parallel, methods related to Design for disassembly can be used for non-destructive recycling purposes. Therefore, the Design for EoL is based on the evaluation of various aspects about the disposal phase of the product, adopting the possible End-of-Life strategies aimed to reduce the environmental and/or economic impact of the product at the End-of-Life.

4.4 Design for life-cycle

The three DfX types introduced in the previous sections aim at improving a particular feature or characteristic of the product through peculiar considerations and choices during the design phase. However, in recent years, the prevision and management of entire product life-cycle during the design phase has emerged as a critical area for investment (Kiritsis et al., 2003). Not coincidentally, in the literature there is also a design approach that looks at the

entire life-cycle of the product, that is Design for life-cycle.) The definition of Design for Life-Cycle (DfLC) adopted in this paper is the following: Design for Life-Cycle aims to minimize the costs emerging during the entire product life-cycle (TCO and LCC reduction) from the concept to the disposal, while ensuring the achievement of product target performances concerning quality and functionality (Eubanks, 1993). Design for life-cycle is one of the most suitable DfX type for the implementation of a use/outcome focused PSS business model. In this case the provider is responsible for all life cycle costs (LCC), which provides a powerful incentive to design a product that minimizes the overall life cycle cost (life-cycle extension and minimization of operating cost). The customer does not buy the product or system but pays a variable fee that depends on its actual usage of the product or on the achievement of a contractually-set result. All the DfX options in this case are relevant, but in particular it is very important to adopt a Design for Life Cycle approach.

5. LEVEL 2: The DfX process model

Considering that DfX types only refers to a general approach adopted during the design phase, for a company it is important to identify a series of practical actions to be implemented in order to improve the desired product features. In literature there are several contributions about potential DfX levers to be implemented and most of them are incident to physical design. Concerning the DfX framework, two tools have been developed in order to help companies in the identification of the relevant DfX options and levers to be implemented. Both tools have been developed as managerial tools in order to make them easy to be used and addressed also to small and medium enterprises that often have not the capabilities to understand and implement mathematical models or algorithms. Both tools have been developed and tested with three companies in the “T-REX” project funded by the European Community's Seventh Framework Programme. The two tools are: Tool DFX1 - DfX brainstorming tool; Tool DFX2 - DfX Gap assessment and levers selection.

5.1 Tools DFX1: DfX brainstorming tool

The tool DfX1 is organized as a brainstorming with a series of questions to which companies are required to answer depending on the configuration of the new BM. In particular it leads the practitioners to evaluate (Figure 2):

- Which are the products and the customer segments that will be involved in the envisaged PSS business model?
- Which product features and/or virtues have to be enhanced to implement the envisaged PSS business model?
- Which the expected configuration of the new business model?
- Which are the new services that will be provided?

The tool has to be used as a guideline during the discussion where the ideas can be sketched out. Moreover, it helps practitioners in understanding: which are the DfX types to be focused on, according to the new BM configuration, and the products/customer segments involved. Finally, it guides the companies in choosing the product features to be enhanced based on the services that will be delivered in the new BM configuration based on the choice of the company.

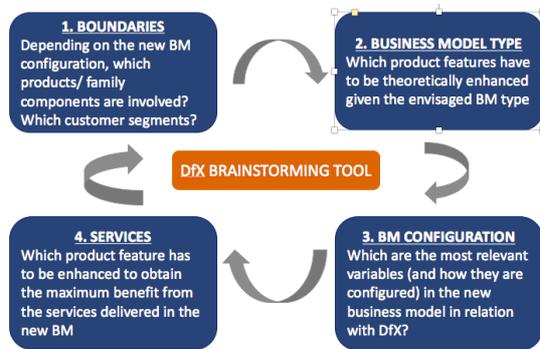


Figure 2: DfX brainstorming tool

5.2 DfX Gap assessment and lever selection tool

The tool DfX2, “Gap assessment and lever selection”, evaluates the suitable practical actions to be implemented by the company in order to adopt the envisaged PSS business model. This tool has been developed according to two different phases. The first step has concerned the identification of a series of DfX levers that could be potentially implemented by a company who wants to move towards a PSS business model. The levers are practical actions and they were identified in collaboration with the use cases participating in a EU funded project involving companies, universities and research centres in the implementation of a methodology to implement a service-oriented business model. The levers considered in the presented framework, are organized in three categories: Design, Organisation and Technology. First, design levers concern specific hard design precautions that can be adopted by the designer of the product. Second, organisational levers are related to potential changes in the work methodology of the company (e.g adoption of multidisciplinary teams), partnerships (e.g. co-design with suppliers) and culture (e.g. adoption of TCQ techniques) that may both directly and indirectly influence the product design. Finally, technological levers are related to technological devices that could be attached to the product (embedded or not) in order to improve some specific product features. 27 practical levers have been identified and each lever has been related with one (or more) of the four DfX options identified in the Level 1 of the framework. Table 3 shows the number of levers identified for each category and the connection with each DfX option (one lever can be connected to more than one DfX type).

Table 3: DfX practical levers

Category (n. of levers)	Reliability	Serviceability	EOL	Life-Cycle
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Design (12)	2	7	4	8
Organization (10)	6	4	2	7
Technology (5)	-	5	-	4

Table 4 shows one DfX lever example for each category.

Table 4: DfX levers examples

Category	Dfx lever	Description and reason for impacts
Design	Components compatibility (with older versions) enhancement	Enhancing compatibility of newer components with older product versions improves upgradability. In this way customers don't have to buy the entire product in order to update the older one. Moreover, the company achieve advantages in terms of spare parts management.
Organization	Feedback from customers	Systems aimed at acquiring feedback from customers could be useful in case of future re-design of the product.
Technology	Self-maintenance tools	Self-maintenance tools could help customer to solve particular product failures without the intervention of manufacturer (POKA YOKE). The tool may be paper, web or a screen embedded in the product which help customer (with clear instructions) to solve simple breakdowns or failures of the product

As mentioned before the levers have been thought to be easy to be understood and applied, avoiding mathematical methods and algorithms (as found in literature) but strongly managerial. The second phase of the tool development has concerned the identification of a list of gaps that companies likely have to fill in order to implement a PSS business model. These gaps have been thought by research according to 4 specific goals that are generally addressed in implementing a PSS business model, namely: decrease maintenance costs, increase reuse, extend product life-cycle and improve TCO/LCC. These gaps have been extrapolated considering the potential consequences of the application of each DfX levers identified in the previous phase. Table 5 shows the number of gaps identified for each goal with some examples.

Table 5: Likely gaps to be filled by the company

Goals	N. of gaps identified	Examples
Decrease	7	• Enhancement of product

maintenance costs		<p>reliability in order to reduce the fault rate and increase the MTBF</p> <ul style="list-style-type: none"> • Enhancement of product accessibility/inspectability to reduce time/cost needed for maintenance operations • Increase of recyclable materials used into the product
Facilitate reuse	6	<ul style="list-style-type: none"> • Improve the components' compatibility in order to make them usable in another product at the end of a product lifecycle • Enhancement of product reliability in order to reduce product downtime
Reduce LCC/TCO	6	<ul style="list-style-type: none"> • Elaboration/improvement of methods and models able to consider costs that will emerge in the product lifecycle (during the design phase) in order to choose the best design alternative • Improving models and techniques able to identify signals in the product which indicates an improper functioning of the product (failure detection)
Extend product life-cycle	6	<ul style="list-style-type: none"> • Implementing tools for collecting data (both from the product and customer) so that it is possible to improve the product design and extend its lifecycle

After that, each DfX lever has been investigated in order to understand the potential impact with each gap. Therefore, an evaluation of which are the levers that most are suitable for that gap was carried out by the researchers in collaboration with the companies involved in the project. Indeed, the application of the tool DfX2 by the company is divided in three different steps:

- STEP 1: Company is required to state the priority on filling each gap based on the configuration of the new BM defining a level (HIGH, LOW, NONE). Moreover, for each gap, companies are required to express the motivation of their answers and potential improvements that could be achieved to fill the gap in object;
- STEP 2: The most appropriate DfX levers, based on the answers provided by the company in the previous phase, are chosen. Indeed, for each DfX lever related to that gap, a rating is given based on the answers provided about the linked gaps, namely: 3 points for HIGH, 1 point for LOW and 0 points for NONE. Then a ranking is created based on the ratings obtained listed in descending order.
- STEP 3: After the ranking has been developed, companies are required to give their opinion on the

levers in the first positions of the ranking formed in the previous phase stating if the lever is effectively applicable in the reference context of the company and how.

6. Conclusions and limitations

Because of several competitive pressures, manufactures are nowadays pushed towards evolutive business model configurations focusing on the provision of offer characterized by the presence of physical products and intangible services. Indeed, more and more companies are moving to PSS business models where the focus is not the sale of the product (ownership) but rather the usage (e.g. renting, pay-x-use) or performance (e.g. pay-x-performance). This new trend is extended to different capital goods industries where there is an increased emphasis on service business. In line with the objectives of the journey towards a more service-oriented business model, the product has to be designed in order to present specific features that makes efficient and effective the provision of product-related services. The adoption of specific DfX techniques may help companies in considering all these aspects, during the design phase, in order to evaluate all the product life-cycle. Through a literature analysis, this paper has presented a DfX typology encompassing 4 DfX types that may be considered by companies which want to move or to implement a PSS business model, namely: Design for Reliability, Design for Serviceability, Design for End-of-life; Design for Life-cycle. The impacts of each DfX type has been evaluated according to the PSS BM typology developed in Adrodegari et al. (2015). Moreover, in order to help practitioners in adopting the DfX approach, a toolkit has also been developed. This toolkit aims at evaluating practical actions to be taken in order to improve the product design based on the configuration of the envisaged PSS business model. The toolkit consists of two related tools: 1) DfX brainstorming tool; 2) DfX gap assessment and levers selection tool. As with any research, this study is not without limitations. On the one hand, the typology developed and the impacts on a PSS business model is carried out in line with a specific business model typology (Adrodegari et al. 2015). The main managerial implication of this work is the provision of a practical toolkit that practitioners can use in order to implement a PSS strategy. Indeed, according to the PSS type addressed by the company strategy, the DfX framework encompasses all the relevant elements to be considered in designing suitable products to be services with different types of services. Next studies about this topic may involve the use of other PSS typologies (e.g. Tukker 2004) in order to address a more generalized result. On the other hand, even though the development of the toolkit was carried out in collaboration with three use cases, it is possible that some practical levers specific of some industries not involved in the T-REX project are missing. Finally, next contributions about this issue may be aimed at evaluating the BM transformation in a company after the adoption of the tools presented in this paper.

Acknowledgements

The work described in this document has been conducted as part of the project T-REX (Lifecycle Extension Through Product Redesign And Repair, Renovation, Reuse, Recycle Strategies For Usage & Reusage-Oriented Business Model), research project funded by the European Union Seventh Framework Programme (FP7/2007-2013) under grant agreement no 609005. For more details visit: <http://t-rex-fp7>

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