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The industrial symbiosis in the product development: an approach through the DFIS

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Abstract

Industrial symbiosis is characterized mainly by the reuse of waste from one company by another company as raw material. This concept has advanced in the sense that companies seek to develop this type of relationship. We believe that one of the next steps is to consider industrial symbiosis in the product development. It is in this context that enters the DFX (Design for X), as it seeks to maximize the product features with respect to the approach to which the X refers. This work aims to examine two possibilities; the first is to consider the industrial symbiosis within the Design for Environment, since it is an already existing approach that considers the environmental aspect, so industrial symbiosis would be just another factor. The second possibility is the proposal of the Design for Industrial Symbiosis (DFIS) and its systematization in an application method. Considering the industrial symbiosis in the product development would also bring financial benefits, not only environmental.

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Keywords: Industrial Symbiosis; Product Development; DFX; Environment; DFIS.

1. Introduction

Industrial symbiosis is understood as an approach within the industrial ecology that involves different companies in the exchange of physical materials, such as by-products or waste, energy and water [1]. The case of Kalundborg, in Denmark, is the seminal example of the emergence and development of this phenomenon [2, 3]. Industrial symbiosis in Kalundborg began in the 1970s when some industries shared water in a self-organized way [1, 4, 5], and it has evolved over the years, now having material exchanges in about 20 different companies [5].

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Besides these works already mentioned, other works have been published citing the industrial symbiosis development in an attempt to understand and explain the factors that led the case to success, as noted in [3]. There are also easily found in the literature, cases of other parks that developed the industrial symbiosis, such as the cases of [6, 7]. A great effort has been employed in the attempt to systematize a model, methodology or tool to assist in the planning of new kernels of industrial symbiosis, as can be seen in the works of [8, 9]. Other studies [10, 11] have applied existing methodologies such as Material Flow Analysis and Life Cycle Assessment in the evaluation of existing industrial symbiosis networks. Other more recent approaches are the proposition of performance indicators for the industrial symbiosis measurement [12, 13, 14] and the development of computational simulation models to represent the industrial symbiosis [15, 16, 17]. Finally, industrial symbiosis has also been related to the term Circular Economy [7, 18].

The industrial symbiosis is studied through different approaches, but it is possible to notice that most, if not all, considers the industrial symbiosis from the point of view of the industrial park administrator, known as broker. Two clear examples are the works [14, 9], where the first [14] propose a performance indicator to measure the industrial symbiosis that should be used mainly by the broker, while [9] present a methodology to support the local authority, that is the administrator of the park, during the industrial symbiosis development process.

It lacks approaches that allow considering the industrial symbiosis through an intra-firm angle, that is, from the company point of view, where it is the main actor in the development of industrial symbiosis. We see as an opportunity to consider the industrial symbiosis in the product development, as this is a way for companies to pursue innovation to remain competitive within the industrial environment [19]. Product development can alter parts of the supply chain and thus extinguish existing symbiosis networks or, on the other hand, create opportunities for the emergence of new symbiosis networks. In addition, [4] state that significant gains with respect to industrial symbiosis can also be achieved in product design.

This paper aims to examine two possibilities regarding industrial symbiosis in product development. The first is to consider industrial symbiosis within Design for Environment (DFE), an already existing approach that considers environmental aspects as features to be maximized in product development, so industrial symbiosis would be just another factor to be considered. The second possibility is the proposal of the Design for Industrial Symbiosis (DFIS), and its systematization in an application method.

2. Literature review

2.1. Industrial symbiosis and eco-industrial park

One of the most replicated definitions of industrial symbiosis is that proposed by [1], which defines it as a phenomenon that engages separate industries in a collective approach through the exchange of materials, energy, water and by-products. More recently, [20] presented an updated definition of industrial symbiosis, which according to the authors carries several concepts of the definition proposed by [1]: “Industrial Symbiosis engages diverse organizations in a network to foster ecoinnovation and long-term culture change. Creating and sharing knowledge through the network yields mutually profitable transactions for novel sourcing of required inputs, value-added destinations for non-product outputs, and improved business and technical processes” [20, p. 29]. As stated by [21], industrial symbiosis can be characterized through three symbiotic transactions: utilities sharing, services joint provision and by-products exchange.

The industrial symbiosis is catalyzed by the geographical proximity between firms [1]. And according to [22, 23], industrial symbiosis is the phenomenon that characterizes an Eco-Industrial Park (EIP), which in turn is defined as a community of companies located in a common place that seek to improve environmental, social and economic performance through cooperation [24].

2.2. Design for X

Design for X (DFX), also called design for excellence, is an approach used in product development that aims to improve or maximize aspects of the product being developed, or of its life cycle, where the aspects to be improved or maximized are with respect to X [25, 26, 27, 28, 29]. An example is the DFE, which aims to support the designers in the development of products that have a reduced environmental impact [30].

According to [26, 31], the DFX can be divided into two varieties. One variety is where the product must have the X-aspect, called by [26] as Virtue DFX and by [31] as Product Scope DFX. And the other variety is where the X-aspect is optimized at some point in the product life cycle, called Life Phase DFX by [26], and System Scope DFX by [31].

A wide variety of DFX is found in literature, being of Virtue DFX (or Product Scope DFX) or Life Phase DFX (or System Scope DFX): design for manufacturing, design for assembly, design for quality, design for reliability, design for disassembly, design for maintainability, design for obsolescence; design for cost, design for usability, design for supply chain, design for logistics, etc. [26, 31, 28].

With respect to the DFX structure, it can be presented through five categories [31, 28]: (i) **Guidelines**, which provide the direction to be followed; (ii) **Checklists**, that describe items that must be taken into consideration; (iii) **Metrics**, which evaluate the product with respect to the considered aspect; (iv) **Mathematical models**, which involve validated equations and formulas; and (v) **Methods** as a systematic structure for design verification, and may involve some of the other categories.

The guidelines, that are the basis of a DFX, can be applied through four approaches [32]: (i) strategy identification and relevant guidelines implementation; (ii) use of guidelines as ideas generators; (iii) specialized database use for selecting relevant guidelines; and (iv) use of a set of guidelines for the concepts evaluation.

Among the types of DFX presented and identified in the literature, the closest to the objective of this work, that is considering the industrial symbiosis in product development, is the DFE (Design for Environment). Through a thorough research, [30] identified 67 guidelines reported in the literature for the application of DFE and divided them into 6 principles. More recently, [32] updated this list to 76 guidelines, maintaining the six principles, that are: (i) maximize availability of resources; (ii) maximize healthy inputs and outputs; (iii) minimize use of resources in production and transportation phases; (iv) minimize consumption of resources during operation; (v) maximize technical and aesthetic life of the product and components; and (vi) facilitate upgrading and reuse of components. However, among the guidelines identified by [32], there are no guidelines that contribute directly to industrial symbiosis.

3. Approach

As already presented, this paper aims to investigate how industrial symbiosis can be inserted in the context of product development. For this purpose, two alternatives are presented: the first is to consider the industrial symbiosis within the DFE, while the second is to propose the creation of a new DFX, the Design for Industrial Symbiosis (DFIS). For both alternatives, it is necessary to propose guidelines to support designers in the product development so that industrial symbiosis is an aspect to be pursued. Based on the industrial symbiosis definitions presented, we propose the following guidelines:

- **Use by-products or waste from other companies as raw material.** This guideline aims to make the designers consider the use of by-products and/or waste of other companies as raw material in the production of the product. It is necessary that the designers have knowledge of the waste and by-products generated by the companies located in the same industrial park or that have geographical proximity, since, as already presented, the industrial symbiosis is catalyzed by the proximity between the companies [1].
- **Generate by-products or waste that can be reused as raw material by other companies.** The goal of this guideline is to guide designers to develop a product whose by-products and waste generated in the production process can be used by other companies as raw material. To meet this guideline it is necessary to know what by-products or waste the nearby companies have the potential to use or are already using from other sources. It is also necessary to understand what materials and processes can generate such by-products or waste.
- **Take advantage of other companies' utilities in the production process.** Industrial symbiosis is also characterized by the sharing of utilities among companies, such as energy, heat and steam. This guideline aims to

verify the possibility of using the excess utilities from nearby companies in the production process of the product. It is necessary to be aware of the surplus utilities of nearby companies.

3.1. Industrial symbiosis in the DFE

The first alternative in considering industrial symbiosis in the product development is to incorporate the proposed guidelines into the existing DFE guidelines. Thus, the industrial symbiosis would be just another perspective of this DFX. As previously mentioned, [32] identified the DFE guidelines available in the literature, reaching 76 guidelines divided into six principles. With the incorporation of the three guidelines proposed, we can compose a new principle, or divide them among the existing ones.

If the three proposed guidelines compose a new principle, it could be named "maximizing industrial symbiosis." However, if they were divided into existing principles, they should be classified as follows:

- Guideline "Use by-products or waste from other companies as raw material" in the principle "maximize healthy inputs and outputs".
- Guideline "Generate by-products or waste that can be reused as raw material by other companies" in the principle "maximize healthy inputs and outputs".
- Guideline "Take advantage of other companies' utilities in the production process" in the principle "minimize consumption of resources during operation".

The application of the three proposed guidelines competes with the other DFE guidelines. They can be applied through checklists, metrics, mathematical models or methods that are already used in DFE applications.

3.2. Design for industrial symbiosis (DFIS)

The second alternative in considering the industrial symbiosis in the product development is to propose a new DFX, the Design for Industrial Symbiosis (DFIS). The DFIS is composed only by the three proposed guidelines, presented previously. Since there are only three guidelines to follow, they do not have to compete with others and do not need to be prioritized, so we can synthesize them in an application method. The method is based on a set of steps, as shown in Fig. 1.

The first step in the DFIS application is to identify the by-products and wastes generated by nearby companies as well as surplus utilities. It is also necessary to identify which by-products and waste these companies can absorb as raw material. The need to identify this information has already been informed in the presentation of the three guidelines.

For the solution options identification (second step) a morphological matrix should be used to visualize the product functions, different solution principles for these functions and by-products and/or waste that can be used in the product development, according to the scheme presented in Fig. 2.

The rows are composed by the product functions, which describe the required capabilities for the product to be able to perform its specifications. The columns contain the solution principles in order to meet these functions and different possibilities of by-products and/or waste that can be used to meet the chosen solution. Only one solution principle can be chosen for each of the product functions. Next, the combination possibilities for the product constitution are analyzed.

A product example consisting of three functions is shown in Fig. 2, where each solution has the possibility to use different by-products and/or waste. The paths indicated in Fig. 2 represent the combination possibilities for the product constitution. In the example, two solution options are identified, one corresponds to the solid line and the dashed line represents the other.

In the third step, the solution options are evaluated in relation to the three proposed guidelines. The evaluation can be qualitative, where it is verified if the guidelines are met by the solution options and which solution option is the best choice in terms of industrial symbiosis. The evaluation can also be quantitative, through the application of an industrial symbiosis indicator in the solution options identified. For the evaluation with a performance indicator,

[33] identified, through a systematic literature review, eight papers that proposed industrial symbiosis indicators, among which the Industrial Symbiosis Indicator (ISI) by [14] stands out.

The decision gate aims to verify if the best-evaluated solution is in line with the DFIS guidelines. The next step is the application of the chosen solution in the product production. The last step is the continuous improvement process. In this step, industrial symbiosis indicators can be applied to compare the previous situation with the new one after DFIS application.

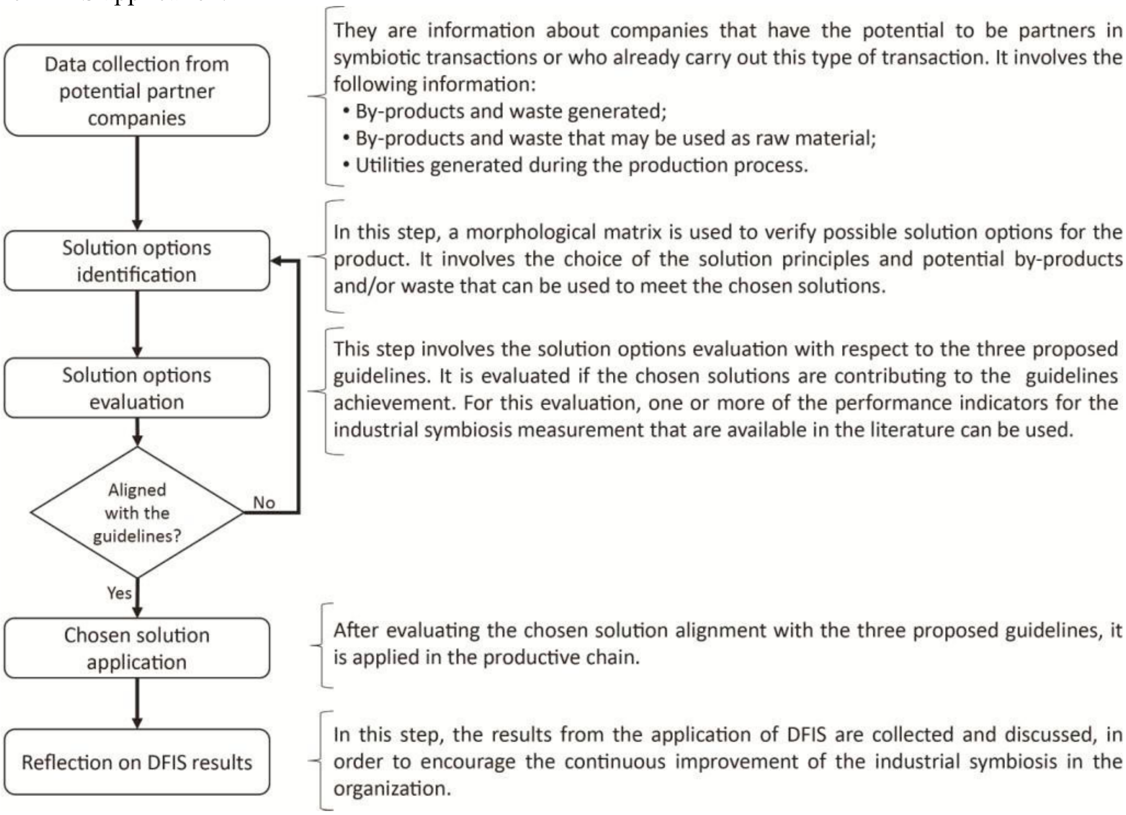

Fig. 1. DFIS application method

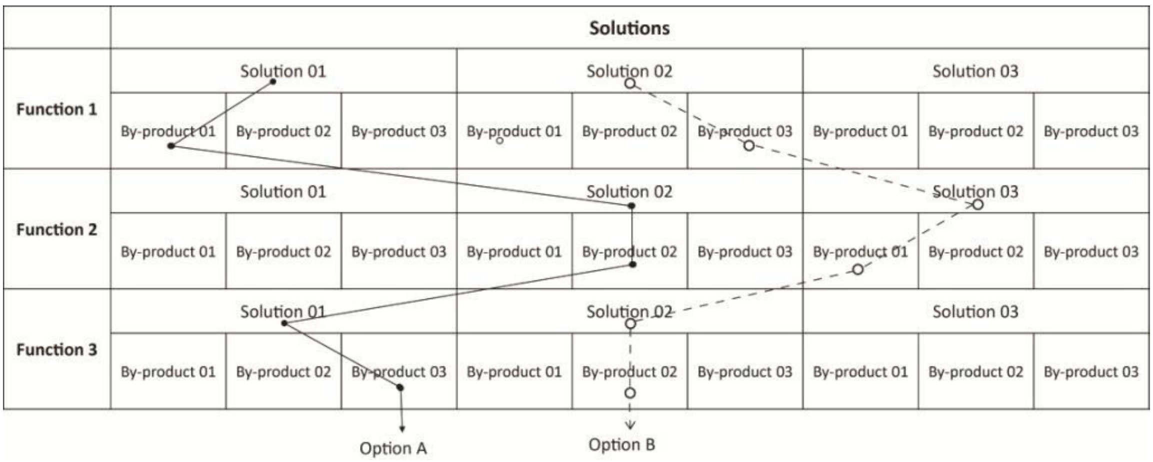

Fig. 2. Morphological matrix for the DFIS application

4. Example of the morphological matrix application

In order to illustrate a hypothetical example of the morphological matrix application, it was selected a project developed by undergraduate students in the industrial engineering course of the São Carlos School of Engineering, University of São Paulo. The product of the project was a selective waste collection car, a common activity in Brazil. Fig. 3 shows the car project, which is divided into 4 functions: Carry material; Support (structure); Move; Push. In addition, Fig. 4 presents the morphological matrix for this product, already filled with some hypotheses of solution principles and by-products and/or waste.

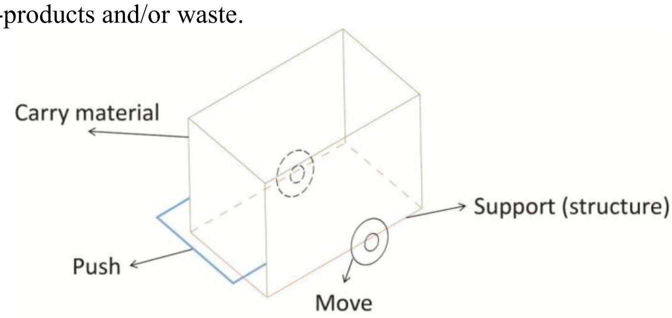

Fig. 3. Project of the waste collection car

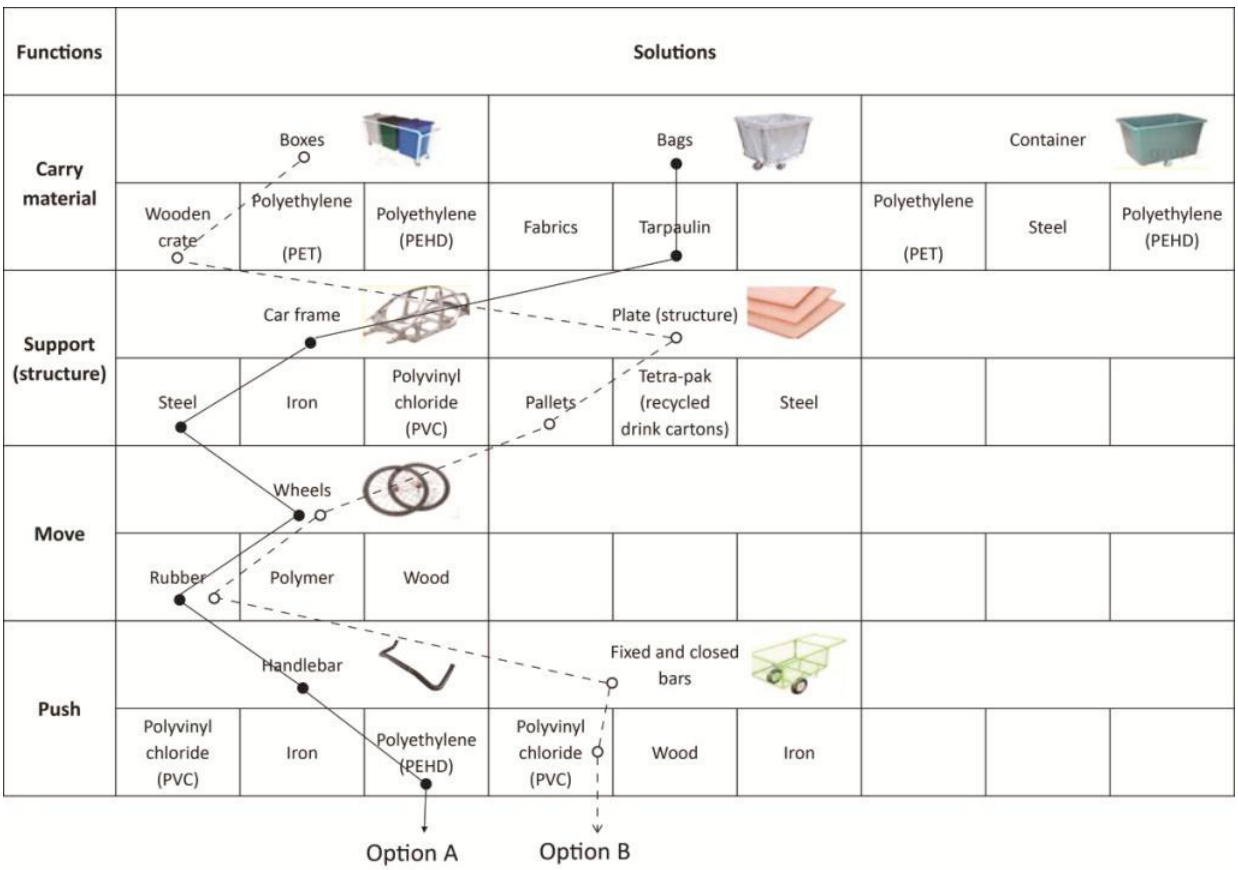

Fig. 4. Morphological matrix for the waste collection car

Each of the options is composed by a set of solutions and by-products in order to meet the product functions. After identifying the options through the morphological matrix, as shown in this example, the possible options should be evaluated according to the three proposed guidelines. At this point, it is also important to know the waste, by-products and spare utilities generated by potential partner companies, as well waste and by-products that they can use as feedstock.

5. Discussion

The objective of this work, already presented in the introduction, was to insert the industrial symbiosis in the context of product development through two approaches. The first was to consider the industrial symbiosis within the DFE, while the second was to propose a new DFX, the DFIS, and its systematization in an application method. The two proposed approaches have a significant difference. To insert the industrial symbiosis in the DFE implies sharing the attention of the three proposed guidelines with the other existing guidelines of this DFX, and its applications depend on its selection and prioritization. While in the creation of DFIS, the three proposed guidelines are the only ones to be followed, so they do not need to be selected or prioritized among others.

Regarding the use of the three proposed guidelines in conjunction with the existing DFE guidelines, if on the one hand the industrial symbiosis guidelines can be left in the background with the prioritization of other guidelines, on the other hand the DFE can provide a more holistic result that considers more environmental aspects in product development, including industrial symbiosis.

In the application of DFIS, using the application method, the design is directed to the industrial symbiosis, being more likely to achieve a product development that considers this aspect. However, other environmental aspects can be overlooked if it is not paid attention to these other factors.

6. Conclusion

Considering the industrial symbiosis in the product development can contribute not only to the industrial symbiosis development of the park in which the company is inserted, but also to achieve positive financial results, since there is the possibility of using cheaper materials and utilities, as well as the commercialization of by-products and waste generated.

The three proposed guidelines application, whether in DFE or DFIS, can also be used to identify opportunities for products that already exist, not only for the new products development. That is, the existing products would be changed in order to consider the industrial symbiosis in its production.

Two main contributions were presented. The first is the three guidelines proposal for considering the industrial symbiosis in product development. The second is the systematization of these guidelines in a method for the DFIS application. However, this work is restricted to the proposals and exploration of the possibilities presented. So far, no empirical or practical work has been done regarding the proposed theme.

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