A Novel Knowledge Repository to Support Industrial Symbiosis

Miriam Benedetti, Maria Holgado, Steve Evans

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Miriam Benedetti*, Maria Holgado, Steve Evans

Institute for Manufacturing, University of Cambridge
17 Charles Babbage Road, CB3 0FS Cambridge, UK
{*mb2132, mh769, se321}@cam.ac.uk

Abstract. The development of tools and methods supporting the identification of Industrial Symbiosis opportunities is of utmost importance to unlock its full potential. Knowledge repositories have proven to be powerful tools in this sense, but often fail mainly due to poor contextualization of information and lack of general applicability (out of the boundaries of specific areas or projects). In this work, a novel approach to the design of knowledge repositories for Industrial Symbiosis is presented, based on the inclusion and categorization of tacit knowledge as well as on the combination of mimicking and input-output matching approaches. The results of a first usability test of the proposed tool are also illustrated.

Keywords: Industrial Symbiosis • Mimicking mechanism • Knowledge repository • Industrial synergies • Resource efficiency

1 Introduction

Industrial Symbiosis (IS) is nowadays one of the most prominent sub-disciplines of Industrial Ecology (IE), a discipline advancing sustainable industrial ecosystems through paradigms that support interactions and exchanges between industrial flows and their surrounding environment [1]. It is, even if still a relatively new field, a growingly accepted paradigm for processing waste into material, energy and water with benefits to participants measured by economic, environmental and social gains [2]. In practice, it means that manufacturers can make better use of all inputs to their processes through exchanges of waste, by-products and energy with other companies/sectors [3].

However, in spite of the potential benefits of IS, there is still an evident implementation gap, with practitioners failing to fully exploit its possibilities [4]. Part of this gap is certainly given by the high degree of characterization needed for the design of IS in different contexts, as well as by the huge number of factors influencing its development, such as technical, political, economic and financial, informational, organizational and motivational [5]. In addition, unlike commodities such as recycled metals, waste materials are typically nonstandard or highly variable in composition, thus the process of exchanging them can be more challenging [1].

adfa, p. 1, 2011.

It is well acknowledged in literature that IS opportunities identification can benefit from the creation of knowledge repositories [1, 6, 7]. Thus, over the last years, IS researchers and practitioners have made several efforts in order to create knowledge repositories for IS [6], and the present work builds on related literature to create a novel knowledge repository combining main pros and addressing main cons of existing ones.

The main research question addressed in this paper is therefore: *How to effectively design a knowledge repository to identify new ideas and opportunities for IS?* In the following paragraphs, a review of main approaches to the design of knowledge repositories to support IS opportunities identification will be presented, aimed at identifying strengths and weaknesses for each of them. Then, the design of a novel repository based on these premises is described, first of all defining the design process and then illustrating main outputs of its application. Finally, some planned future developments to improve the proposed repository will be discussed.

2 Literature review

The development process for IS, as it is described in literature [6], usually starts with a first, fundamental phase in which opportunities for IS implementation are identified. Opportunities identification can occur in different ways: (i) the company can focus on a specific waste material and develop a new process to transform it into a by-product; (ii) the company can get in touch with neighboring companies and look for potential synergies (this approach is usually facilitated by a third party); or (iii) the company can learn from business cases in which similar companies were involved and replicate successful practices [6]. Especially considering the last two approaches, in which gathering and analyzing data from other companies is fundamental, several tools have been developed over the last years trying to facilitate opportunities identification and to partially fill the implementation gap. These tools are generally either based on workshops (as described for example in [8]), or on Information and Communication Technology [6, 7, 9]. Anyway, the effectiveness and general applicability of these tools is often still unclear [6], one of the main shortcomings being the fact that they do not address contextualization issues. The opportunities identification phase is in fact one of the most influenced by contextual factors and, being a very early one, can condition the whole development process. Thus, the creation of tools designed ad hoc to facilitate this stage is of utmost importance, since it can potentially enable and ease following phases, contributing to face the contextualization challenge. There are two main approaches usually followed to design knowledge repositories for IS: the first one is based on the mechanism of "relationship mimicking", while the other one is based on the mechanism of "input-output matching" [1, 6].

The "relationship mimicking" mechanism involves mimicking successful relationships employed by similar organizations. Triggering mimicking mechanisms by the means of knowledge repositories is a process that has proven to be positively practical and easy to implement [6]. In fact, this requires enabling information exchange by matching companies from similar industrial sectors, a process that is supported by existing standardized classifications for industry. These classifications, as for example the statistical classification of economic activities in the European Community [10], are already well known and widely used. A successful linkage can therefore be explicitly designated by two codes, one for each of the industries it connects [6].

The creation of such explicit linkages is not as easy in the "input-output matching" approach. This approach builds on the definition of available resources for one organization, and on the identification of complementary resource requirements for another organization [1]. It usually leads to the creation of new exchanges in a much more straightforward way compared to mimicking approach, as it directly links the demand and offer for a specific material. Nevertheless, it is generally successful only when applied to closed systems (one famous example of a closed system is Kalundborg, Denmark [11, 12]) and/or to facilitated systems, where synergies are established, by third parties among pre-selected industries, basing on their geographical proximity or on their existing relationship and mutual trust [1]. A knowledge repository designed with an input-output matching approach tends to fail when not strongly supported by waste management experts and when not applied to closed systems, mainly because the definition of a common and standard classification of waste is still a challenge. Nowadays, the development of open IS models enabling unrestricted and wider participation of partners as well as competitive terms in exchanging materials and energy is becoming more and more common, as it is considered to be consistent with the dynamic nature of IS networks [1]. Therefore, the input-output matching approach needs to be improved and potentially combined with the mimicking approach, creating a sort of new, hybrid approach, in order to still be considered effective.

Existing knowledge repositories for IS, both designed using a mimicking approach and an input-output matching approach, have two main limitations. The first one is that they are generally lacking tacit knowledge content and the second one is that they often only include synergies created within a specific project or in a specific geographical area, losing general and trans-contextual validity [6, 7, 13].

Tacit knowledge is the kind of knowledge residing within individuals or a company, difficult to express in written forms [14] (e.g. expertise and roles of people to involve in the IS development process, factors determining the success of IS implementation, effort needed to implement IS exchanges, etc.). It is opposite to explicit knowledge, which is defined as information that is easily communicated, codified, or centralized using tools such as statistics [6]. Tacit knowledge transfer offers tremendous opportunities to enable Industrial Symbiosis networks, as it specifically addresses contextualization challenges [15, 16]. Thus, it could help avoiding practitioners' biases towards their own expertise or particular industries they wish to serve, informing them about new and unexplored potential synergies as well as required associations, know-how, expertise and engineering solutions [1].

In the present work, the design of a knowledge repository based on the mimicking approach, but trying to integrate positive features of the input-output approach as well as a substantial tacit knowledge content, without losing simplicity in use and effectiveness is presented. This work represents the first step towards the creation of a repository of potential opportunities for new symbiotic exchanges.

3 Methodology for the design of a new knowledge repository

A preliminary review of IS case studies presented in literature set the basis for the tacit and explicit knowledge to be included in the knowledge repository, taking into account main knowledge transfer needs highlighted from previous IS development experiences. The tacit knowledge content has then been classified, while the explicit knowledge content has been codified (mainly associating existing and widely adopted codifications to relevant pieces of information, i.e. industrial sector of companies taking part in symbiotic exchanges and materials exchanged) in order to improve the repository usability and to make the content easily accessible to final users. Thus, a first design of the repository's structure has been defined.

After that, the structure of the knowledge repository has been shown to a group of researchers and industrials already familiar with IS topics, ad their feedback has been used to consolidate it as well as to define potential use processes.

A further literature review has been performed and the knowledge repository has been populated with a set of 46 different case studies set in 16 countries across the world (28 in Europe, 12 in Asia, 4 in America and 2 in Australia), providing a wide overview of different contexts in which industrial symbiosis has emerged so far. (426 symbiotic exchanges are described within the considered cases). It is important to mention that both scientific and non-scientific literature have been considered for database population. This has allowed taking into account also whitepapers and industrial presentations other than scientific papers, thus including in the knowledge repository also simple but effective forms of Industrial Symbiosis that are usually left out of academic research.

Eventually, data collected in four different industrial companies have been used to perform a first usability test of the knowledge repository, evaluating its ability to inform companies on potential IS opportunities.

4 Results

The main output of the design process illustrated in the previous paragraph is a knowledge repository structured in two different and connected sections: a library of case studies and an exchanges database.

Within the library of case studies, each case is described according to a precise structure: a brief narrative of the case description is followed by five sections gathering the related tacit knowledge content, which are the results of the tacit knowledge content classification. *Triggering and precondition* factors are identified to describe the main business challenge that was addressed (the starting point for the search of a solution) and the antecedents that made the symbiotic exchange feasible under the described business context. Antecedents are here intended with the same meaning as illustrated in [17], i.e. inputs to understand and analyze the dynamics of industrial symbiosis. The main *barriers* encountered in the specific industrial symbiosis implementation are described, as well as the *approach* used by the individuals / organizations involved in order to overcome those barriers. Then, the *discovery process* (the process initiated by the triggering factors and finalized by the realization of the symbiotic exchange) is explained, highlighting the main steps and efforts made by the involved individuals / organizations. This includes the description of role of facilitators, whenever applicable.

The description of the discovery process within the library of case studies is meant to help companies fully understand the activities necessary to deliver progress towards the IS vision, as it might not be so clear at this stage, resulting in failed or even dissuading implementation attempts.

Each case in the library is identified by a numerical ID, as well as each source (paper, whitepaper, industrial presentation, etc.) used for library population. A combination of these two numerical IDs plus an additional sequential number univocally identifies each synergy described in each case. This numerical identifiers allows to link the library of case studies to the database of exchanges. This database is a spreadsheet, mainly containing explicit knowledge content, in which each row corresponds to an exchange occurring between two different companies.

For each synergy, the industrial sector of the companies involved is identified using the NACE (Nomenclature générale des Activités économiques dans les Communautés Européennes) code [10], while the exchanged material is identified using the European Waste Classification (EWC) [18]. These two codification systems have been chosen due to their wide diffusion among companies, so as to improve the usability of the repository also for users with no or little background on IS topics, and also according to previous research results [1, 7]. The use of the NACE code specifically allows the triggering of mimicking mechanisms, as companies can search the database to find out what exchanges other companies from their own industrial sector have already implemented. The use of the EWC code is instead twofold: on the one hand, it contributes to supporting the triggering mechanism, as companies can search the database to find out what exchanges other companies have implemented with their own waste, while on the other hand it can be considered as a first step for input-output matching, as it suggests potential partners for each exchange.

Eventually, a description of the waste treatment is given wherever applicable, as well as some additional details regarding the synergy (final use of the exchanged flow, availability of flows' quantities and payment details in the original source, level of completion of the synergy).

5 First validation

In order to perform a first usability test of the designed knowledge repository, two initial standard queries have been identified, representing two possible use processes of the library of case studies and exchanges database. Nevertheless, it is important to highlight that additional searches are enabled in both the library and the database, e.g. keyword searches, but have not been considered as standard queries for this first test phase due to their intrinsic variability and higher degree of customisation. They will, however, follow a similar logic as query type A and B (described in the followings).

The two standard queries defined for the usability test are:

- Standard query type A (in red in Figure 1), looking for similar companies (same NACE code);
- Standard query type B (in green in Figure 1), looking for exchanges of similar waste materials (same EWC code).

The last three steps of the two standard queries are identical (in blue in Figure 1), as they are referred to the identification of the case studies within the library that corresponds to the exchanges in the waste database, and to the extraction of tacit knowledge contents.

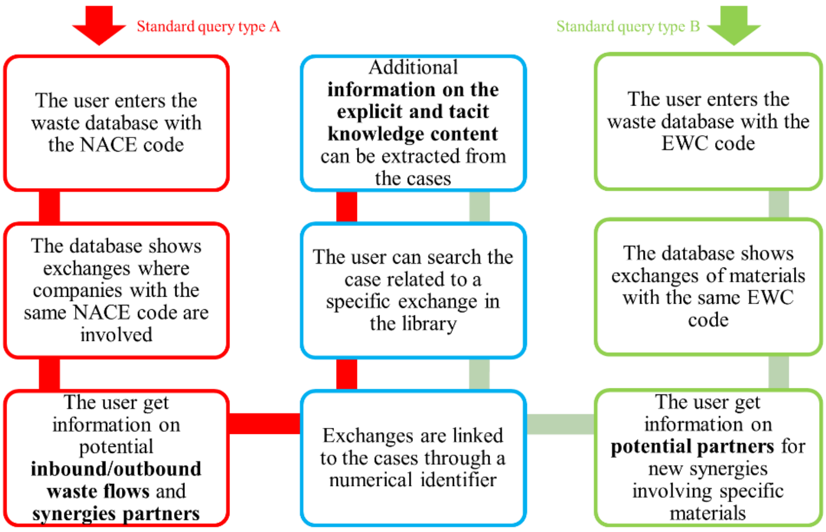

Fig. 1. – Standard queries type A (in red) and type B (in green)

The usability test has been conducted using NACE codes and EWC codes provided by four different companies from the process industry (two chemical companies, a metal parts and a plastic components producer). As a means of example, the following table provides some extracts of the results obtainable from one search using standard query A and from one search using standard query B. Due to confidentiality issues, data presented in the table do not belong to any of the four companies used for testing.

Table 1. Example of results obtained using standard query A (in red) and B (in green).

Code used in the query	*ID of exchange identified in the database*	*NACE of companies involved in the exchange*	*Brief description of the exchange*	*ID of corresponding case in the library*	*Brief description of the case*
17,11 (NACE)	17,27,2	17,11 (donor);	A pulp producer sends ashes de-	17	Relvao industrial park, Portugal. The park has been created with the

		20,15 (receiver)	rived from a combustion process to a fertiliser's manufacturer that uses them as raw material.		support of regional authorities. Symbiosis is a means to reduce environmental impact and increase competitiveness [19].
01 03 09 (EWC)	23,21,12	24,42 (donor) 23,51 (receiver)	An alumina refinery sends red muds to a cement producer.	23	Spontaneous synergy in the Gladstone industrial district in Australia. Symbiosis is a means to reduce environmental impact and face resource scarcity [20].

The database provided examples of flows corresponding to the search criteria for 20% of the analysed codes. Multiple examples of flows have been found for single codes in several cases. The test resulted in the identification of 38 relevant flows, 19 related cases and 26 potential types of partners for exchanges.

6 Conclusions

The novel knowledge repository proposed in the present paper has been tested in four different cases and has proved to be a very promising starting point for the identification of IS opportunities. It enables mimicking and represents a good basis for input-output matching approaches, and its rich tacit knowledge content, referred to different contexts and projects all over the world ensure its effectiveness. In addition, the classification provided for the tacit knowledge content allows an easy and effective usability of the proposed tool.

The main shortcoming of the proposed repository, emerged during the usability test, is the use of the EWC classification, which is sometimes too general when it comes to the definition of produced substances and therefore limits the potential uses of the tool. In fact, it happens that substances that could be reused in different ways are considered altogether as a unique entity by EWC, and the naming of the wastes itself does not always allows a clear matching.

In addition, the number of cases analyzed is still not enough to ensure the general applicability of the repository.

Next steps defined for the improvement of the designed repository are first of all to further analyze and overcome main barriers and limitations of the current configuration of the knowledge repository, related to codification issues, searching modalities and general applicability, and then to make it publicly available online to enable peers and users review and to perform further usability tests.

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References

1. Cecelja F, Raafat T, Trokanas N, Innes S, Smith M, Yang A, Zorgios Y, Korkofygas A, Kokossis A (2015) e-Symbiosis: technology-enabled support for Industrial Symbiosis targeting Small and Medium Enterprises and innovation. J Clean Prod 98:336-352.
2. Trokanas N, Cecelja F, Raafat T (2015) Semantic approach for pre-assessment of environmental indicators in Industrial Symbiosis. J Clean Prod 96:349-361. doi:10.1016/j.jclepro.2013.12.046
3. Manufacturing Commission (2015) Industrial Evolution: Making British Manufacturing Sustainable. http://www.policyconnect.org.uk/apmg/sites/site_apmg/files/industrial_evolution_final_single-paged.pdf.
4. Holgado M, Morgan D, Evans S (2016) Exploring the scope of industrial symbiosis: implications for practitioners. In: Setchi R, Howlett R, Liu Y, Theobald P (eds) Sustainable Design and Manufacturing 2016. Smart Innovation, Systems and Technologies 52. Springer, Cham.
5. Mirata M (2004) Experiences from early stages of a national industrial symbiosis program in the UK: determinants and coordination challenges. J Clean Prod 12(8):967-983.
6. Grant GB, Seager TP, Massard G, Nies L (2010) Information and communication technology for industrial symbiosis. J Ind Ecol 14(5):740-753.
7. Aid G, Brandt N, Lysenkova M, Smedberg N (2015) Looplocal – a heuristic visualization tool to support the strategic facilitation of industrial symbiosis. J Clean Prod 98:328-335.
8. Jensen PD, Basson L, Hellawell EE, Bailey MR, Leach M (2011) Quantifying "geographic proximity": Experiences from the United Kingdom's National Industrial Symbiosis Programme. Resour Conserv Recy 55(7):703-712.
9. Chen PC, Ma HW (2015) Using Industrial Waste Account to Facilitate National Level Industrial Symbioses by Uncovering the Waste Exchange Potential. J Ind Ecol 19(6):950-962.
10. Eurostat (2008) Nace Rev.2, Statistical Classification of economic activities in the European Community.
11. Chertow MR (2000) Industrial symbiosis: literature and taxonomy. Annu Rev Energ Env 25(1):313-337.
12. Jacobsen NB (2006) Industrial symbiosis in Kalundborg, Denmark: a quantitative assessment of economic and environmental aspects. J Ind Ecol 10(1-2):239–255.
13. Alvarez R, Ruiz-Puente C (2016) Development of the Tool SymbioSyS to Support the Transition Towards a Circular Economy Based on Industrial Symbiosis Strategies. Waste Biomass Valor, DOI 10.1007/s12649-016-9748-1.
14. Lam A (2000) Tacit knowledge, organisational Learning and societal institutions: an integrated framework. Organisation Studies 21(3):487-513.
15. Chertow MR (2004) Industrial symbiosis. Encyclopaedia of Energy, pp 407-415.
16. Desrochers P (2004) Industrial symbiosis: the case for market coordination. J Clean Prod 12(8):1099-1110.
17. Boons F, Spekinik W, Mouzakitis Y (2011) The dynamics of industrial symbiosis: a proposal for a conceptual framework based upon a comprehensive literature review. J Clean Prod 19:903-911.
18. European Commission (2008) Waste Framework Directive. Directive 2008/98/EC.
19. Costa I, Ferrao P (2010) A case study of industrial symbiosis development using a middle-out approach. J Clean Prod 18(10-11):984-992.
20. Golev A, Corder GD, Giurco DP (2014) Industrial symbiosis in Gladstone: a decade of progress and future development. J Clean Prod 84:421-429.