

The 9th CIRP IPSS Conference: Circular Perspectives on Product/Service-Systems

Exploration of simulation-driven support tools for sustainable product developmentYasmeen Jaghbeer^a, Sophie I. Hallstedt^{a*}, Tobias Larsson^a, Johan Wall^a^a Blekinge Institute of Technology, 371 79 Karlskrona, Sweden* Corresponding author. Tel.: + 46 455 385511; E-mail address: sophie.hallstedt@bth.se**Abstract**

Global society is encountering many challenges such as climate change, resource depletion, etc., which comes with a set of challenges and opportunities for businesses. Applied research in operational tools and methods that support sustainable product- and service systems innovation, aims to strengthen businesses to overcome these challenges. In recent years, several tools and methods have been developed in the sustainable product development field with focus on modelling and digitalization. This paper explores how sustainability has been integrated in modelling and simulation, and presents results from a literature review with the purpose of highlighting opportunities and challenges in the field. Furthermore, an initial model-based engineering support toolbox (MBE) is presented, with focus on support tools for socio-ecological sustainability integration in the early product development stages.

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1. Introduction

Global society will encounter unprecedented challenges; climate change, resource depletion, chemical pollution and increasing social problems, which collectively represent the major problem of un-sustainability [1]. Those global effects come with a set of challenges and opportunities from a business perspective, such as increased material and energy prices, harsher legislations, etc. Methods and tools to deal with such situations are needed on strategic, tactical and operational levels inside the companies. However, practical methods and tools on the operational level, with purpose of increasing the industry's capability to mitigate and deal with the risk dimension of unsustainable solutions are limited today [2]. Applied research in operational tools and methods that support sustainable product development (SPD), (i.e. a strategic sustainability perspective is integrated and implemented into the early phases of the product innovation process, including life cycle thinking) aims to strengthen businesses to overcome this challenge, in addition to increasing the companies

competitiveness. Several generic support tools have been developed for SPD, summarized in e.g., Salari and Bhuiyan [3], and Buchert et al. [4], which aim to support development teams in integrating sustainability in the early development stages and give guidance in their decisions. However, some challenges are pointed out for these methods: Combination and integration within the product development process; inclusion of a whole life cycle perspective; only a few is validated in companies; and, not based on a clear definition of what the sustainability dimensions mean. Furthermore, few support tools include a long-time perspective which makes it harder to take actions today for issues that might occur in the future while the solution is still operational [5].

It is complicated for companies to do SPD for new innovations for products, services or production methods in parallel of reaching economic targets [6]. The objective of SPD research area is to address the challenges mentioned above, in addition to challenges identified in Hallstedt [7], i.e.: How to identify which the most relevant sustainability aspects to

consider; to what degree a concept performs in relation to a sustainable solution; and how profitability and values can be estimated for a longer time perspective and related to other parameters and requirements. Simulation methods and modelling could assist in better understanding of the sustainability consequences of a decision; by testing multiple interactions between environmental, social and economical sustainability aspects over long-time periods [22]. Even though simulation models have proven to be an efficient approach for product development decision making, it is still challenging to generate models that accurately: transfer qualitative sustainability data to quantitative data; and, compare quantitative sustainability variables against engineering data [21].

1.1 SPD and Product Service Systems (PSS)

PSS is a business model or a design approach that aims to develop functional solutions with both service and hardware dimensions. In general PSS solutions can form a platform to maximise the value of products and materials, and thereby also create circular economy strategies [15, 16, 46]. SPD is one of the approaches that can be combined with PSS to create more sustainable PSS innovations [14], as sustainable PSS has to be designed at an early stage, since it contributes to materials usage, energy consumption, etc. through the entire life cycle of a concept [47].

Despite the increasing interest in sustainable PSS innovation, the shift towards sustainable PSS remains unexplored in most companies [17]. Companies of tradition remain focused on cost efficiency and on solving incremental problems. However, this strategy can be combined with ambidextrous thinking where you balance today's challenges with future potential solutions [18]. The challenges with a lot of information, data and requirements to consider in early stages of product development has made digitalization and big data a growing interest for companies [19]. Data mining techniques for big data can be used to enhance simulation models and to make model driven sustainable PSS innovation more efficient, as it can shorten development cycles and enhance multidisciplinary understanding early in the development phase [20, 21] before the solution is created. Many simulation approaches has been developed for PSS eco-design, such as the work presented by Chalal et al. [49] and Lee et al. [50].

1.2 Purpose

Extracted from the need to build more circular businesses and contribute to a more sustainable society, model-driven decision support for sustainable PSS solutions is of interest. The purpose of this paper is therefore firstly to explore how sustainability has been integrated in current model driven simulation approaches, and to present opportunities and challenges in the field from a literature review. Secondly, to present support tools for SPD in an initial model-based engineering support toolbox (MBE); and, thirdly to present an introductory approach for sustainability simulation support tool to be included in the MBE.

1.3 Paper disposition

This paper is organized as follows. Section 2 presents the research approach, afterwards section 3 illustrates the results of literature studies, opportunities and challenges in the field. Section 4 presents the MBE toolbox to be used in SPD. Followed by section 5, which presents an initial introductory approach for sustainability simulation support tool. Finally a concluding discussion closes the paper in section 6.

2. Research Approach

The research focus here is on SPD and simulation-driven design and model based development, using IT tools and softwares for analysis, modelling, simulation, visualization, and optimization. As mentioned previously there have been an increased development of support tools and methods for SPD. However, there are still few with a simulation-driven and model based approach that also address the challenges pointed out for SPD tools. Hallstedt et al. [23] suggested a modelling and simulation approach to assess sustainability and value consequences of PSS. However, further investigation with regards to sustainability and simulation integration is needed and therefore a literature review was performed to capture opportunities and challenges in the field.

Literature review was conducted based on an adapted version suggested by Biolchini et al. [24], consisting of four main steps:

- Questions formulation: Problem identification and selection of relevant keywords for the search.
- Sources selection: Strings and synonyms identified.
- Studies selection: Define the selection criteria e.g. journal/conference papers, language or time span. Results sorted by the inclusion criteria and analysed.
- Results summarization: Analysis and summarization of selected studies.

The research questions were formulated as: “*What are the main scientific publications regarding integration of sustainability in simulation-driven approaches for SPD?*” and “*What are the challenges and opportunities identified in this field?*”

The main key words used in the search were: sustainability and modelling; sustainability and simulation; social sustainability simulation; sustainability simulation product development; eco design simulation; environmental product development and simulation; and with special attention to synonyms. The search was conducted using a search platform that includes a set of databases, most articles were found through Science Direct, IEEE xplora and Scopus.

The selection criteria included peer reviewed conference and journal articles written in English between January 2005 and October 2016. Search results were evaluated for relevance (e.g., studies related to product development and manufacturing, had a life cycle perspective, included sustainability dimensions) by firstly reading the title, and then reading abstract and key words. If that was not sufficient for exclusion, then the introduction and conclusion were read. At

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