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Subject review
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Lean Product Development Tools for Promotion of Sustainability Integration in Product Development

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Abstract: This article aims to enhance existing understanding of incorporating sustainability aspects during the product development and seeks to fill the gaps regarding the relationship between LPD and sustainability aspects. An up-to-date literature review was performed. More specifically, the expansion of current knowledge covers finding instances in earlier studies that explain the meaning of a sustainability aspect, such as environmental, social and economic aspect. Also, this article focuses on exploring various sustainability aspects using lean product development (LPD) tools and practices. LPD tools and practices that would enable the achievement of sustainability objectives are presented. The findings suggest that the chance for the integration of sustainability in product development comes when integrating sustainability aspects in LPD methods and tools that are used in companies daily. An analysis of the impact of every single LPD tools on individual aspects of sustainability is lacking. The paper concludes with recommendations for future research.

Keywords: lean product development; lean tools; sustainability; sustainability aspect

1 INTRODUCTION

Organizations that are responsible for product development processes and manufacturing have the potential to make a significant contribution to the achievement of sustainability goals within society and can obtain business economic benefits [1]. The new product development (NPD) has to build in the sustainability elements: environment, economic, and social—a sustainable product that is necessary for the industry [2, 3].

Since elementary product properties and characteristics are established during the initial stages, it is crucial to integrate sustainability into the product development process [4, 5]. The sustainability of the future product is determined in this phase [6]. Considering the environmental, social, and economic aspects from the start and include these aspects in the product design is, therefore, the most beneficial method for developing sustainable products. In any case, it is crucial to offer designers and engineers adequate assistance throughout this process [7]. The objectives of developing a sustainable product are to satisfy customers, achieve sustainability in business and meet stakeholders' demands on the industry. Nevertheless, adopting the criteria of sustainable products in the NPD industry is rarely present, especially in the automotive industry [2]. Therefore, the incorporation of sustainability into NPD is still in its infancy [8] and continues to pose challenges for organisations [5].

Lean Product Development (LPD) involves application of lean methodologies to product development, with the goal of developing new or improved products that successfully meet the needs of the market [9]. The increasing adopting of LPD by organizations opens up space to involve sustainable elements in its processes, methods, and tools. This will enable new products to become economically successful, environmentally correct, operationally secure, socially fair, and culturally accepted [10]. Lean philosophy could catalyse to promote better sustainability performance [11-13]. Inclusion of LPD into organizations lean management presents a promising opportunity to also take into account sustainability aspects in product development [14].

Although Lean and Sustainability have been used in many organisations, their integration to the development and design of new products still presents a challenge [5]. Lean and sustainability are increasingly used concepts in companies at all levels. They are used together, unitary and complementary, more and more as a single tool for reducing waste, being also an actual interdisciplinary theme of research [15].

The existing literature and application have not adequately investigated the possible conflicts, interactions, or overlaps between LPD and sustainability. Therefore, it is necessary to adopt a holistic systems approach that promotes integration and synergy in the usage of sustainable product development methods and tools [10]. Examining the relations between lean and sustainability seems like a practical approach to address the inquiry of how to combine and consequently implement these two initiatives [16].

Notwithstanding that, the investigation of lean and sustainability interrelationships has been perhaps one of the most researched subjects in recent times, most of the research efforts do not adequately answer the question: which aspects of sustainability can LPD tools affect? The limited viewpoint of previous investigations results in a fragmented understanding of the synergies between LPD tools and different types of sustainability aspects. Also, this article focuses on exploring various sustainability aspects using LPD tools and practices. It aims to find out what aspects of sustainability engineers in the industry consider in product development.

There is a gap in the literature relating to LPD tools and affected sustainability aspects. Hence, an attempt has been made in this paper to fill this gap.

The paper is structured as follows. After an introduction, the next section provides the research methodology. The following section presents research results followed by a descriptive analysis of the papers gathered and the most important findings. Finally, the conclusions, implications, and future research are outlined.

2 RESEARCH OBJECTIVES AND RESEARCH METHODOLOGY

The objective of this research is to bridge the gaps in the existing literature regarding the relationship between LPD and various sustainability aspects by addressing the following research questions:

- RQ1: Which aspects of sustainability can be influenced in the product development phase?
- RQ2: Which lean product development tools can be used to influence aspects of sustainability?

The first research question will be answered through finding the instances in earlier studies that explain the meaning of a sustainability aspect, such as environmental, social and economic aspect. The second research question focuses on the LPD tools and practices that would enable the achievement of sustainability objectives. In particular, we want to contribute to this field of knowledge by exploring the different types of tools and LPD practices and recognising they can be used to improve sustainability aspects based on the literature. It should be noted that sustainability is considered the unity of all three dimensions: environmental, social and economic.

A comprehensive analysis of the most current literature available was carried out. The purpose of the literature review was to recognise the LPD tools and sustainability aspects used in the product development process. Papers were gathered from international peer-reviewed journal articles and conferences and were extracted from the following online databases: Web of Science and Science Direct. This aligns with the recommendations to use a minimum of two databases for research purposes [12].

Table 1 Sustainability aspect grouped according to the sustainability dimensions and authors

Sustainability aspects	Reference	Sustainability dimension
emissions	[20] , [21], [18], [16], [4], [22]	Environmental
pollution	[20], [21], [18], [16], [23], [22]	
natural habitat conservation	[20], [21], [4]	
consumption of water	[24] , [25], [21], [18], [26], [16], [27], [22]	
consumption of material/ using replenishable resources / reducing the weight / using recyclable materials	[24], [25], [21], [26], [18], [16], [4], [23], [27], [22]	
consumption of energy	[28],[25], [21], [26], [18], [16], [4], [23], [27]	
land use	[24]	
adherence to regulations and certifications regarding material usage /environmental regulations and standards	[29], [25], [21], [4], [22]	
End-Of-Life strategy	[29], [25], [21], [18]	
energy efficiency while using the product /design for transport	[30], [25], [21], [26], [18], [16], [4], [23], [24]	
choosing materials that are not harmful or toxic / phasing out hazardous substances/ avoidance of conflict minerals for product parts and/or its manufacturing	[30], [21], [26], [18], [16], [23], [28], [24], [31], [4], [22]	
promote repair and upgrading/serviceability	[26], [18], [23]	
welfare of employees (including health and safety, career growth opportunities and contentment with the organization)	[20], [21], [26], [16], [23], [31], [24], [4], [25], [22]	Social
welfare of customers (including their health and safety during the production and usage of the product, ensuring customer contentment and rights are met)	[20], [21], [26], [16], [24], [22]	
welfare of community (participation in community development programs, human rights, equity, and anti-corruption measures)	[20], [21], [26], [27], [22]	
avoidance of forced labour, child labour, and corrupt practices	[32], [19]	
availability of quality drinking water, the right to form and join trade unions, promoting gender equality, and access to fundamental knowledge and education	[19]	
quality and durability of the product	[29], [23],	
functional performance	[29]	
product safety and health impact	[29], [21], [18], [16], [31], [24], [4], [25]	
product meets End-Of-Life standards and certifications	[29], [25]	
organizational learning	[21], [16]	
growing divided into: financial gain, expenses, and investments that an organization makes, return on investment	[20], [21], [18], [18], [16], [23], [24], [29], [24]	Economic
innovation potential	[4], [21], [16]	
increased competitiveness, competitive advantage, create economic opportunities	[4], [21], [16], [28]	
energizing employees	[4], [21], [16]	
Research and Development expenses	[29], [18]	
direct and indirect expenses, such as expense of labour and material	[29], [18], [18], [23]	
market profit and quality of products	[29], [21], [27]	
productivity, improvement in employee performance, Design for Manufacturing	[21], [18]	

To ensure that the literature review included current information, the search was restricted to articles and conference papers published in English from 2010 to present. An initial query string was built using keywords (lean AND product development AND sustain*), and a second one using synonyms (lean AND product design AND sustain*). Only the engineering domain was set relevant (At this stage, papers from fields such as arts and humanities, astronomy, and medicine were excluded). The final selection of documents was based on the following criteria: title of the publication or

the text outlined in the paper's abstract. If the initial criteria were not sufficient for exclusion, the next step involved reading the introduction and conclusion of the paper, and if necessary, the entire document was read to make a final decision. The resulting sample was enriched through snowballing.

3 RESULTS AND DISCUSSION

3.1 Sustainability Aspects

It is essential for both professionals and academics to recognize that all three dimensions of sustainability must be addressed at the same time in order to achieve substantial outcomes [17]. The answer to the first research question is given in Tab. 1, which represents an overview of the different sustainability aspects presented in the literature review in a structured way. Aspects of sustainability are listed in table 1 so that they are grouped according to pillars: environmental, social or economic, which is indicated in the third column. The second column shows authors who deal with a certain aspect in their works.

Typically, engineers and designers are not trained to identify the environmental and social consequences of the products they design. To address this issue, straightforward and effective tools are necessary to enable designers and engineers to consider the environmental and social implications of their work while still accounting for the complex nature of sustainability concerns [18].

J. P. Schöggl et al. [18] introduced a qualitative decision support tool for evaluating environmental, economic, and social aspects during the initial stages of product development.

Incorporating sustainability criteria into decision support for the product innovation process is a crucial factor in efficiently integrating a sustainability point of view in the initial stages of product development [4].

R. Gould et al. [19] designed support for using social principles to analyse product concepts.

The conclusion is that there is no lack of works that state aspects of sustainability, but these aspects are mostly included in various models for sustainability assessment. The mentioned articles and models lack a component that would evaluate the impact of the individual tools that designers already use in their work on the mentioned aspects of sustainability. This would make engineers more aware of their own impact on product sustainability through the tools they use and the decisions they make while using these tools daily.

3.2 Lean Product Development tools

Tab. 2 presents the compilation of LPD tools and practices retrieved from the literature. The answer to the second research question is given in Table 2, where are the first column listed LPD tools and practices which can be used to improve sustainability aspects. The second column listed all authors who cited certain LPD tool as influencing sustainability.

The similarities between lean principles and sustainability outweigh their differences. It seems that sustainability, driven by lean principles, still has a significant amount of unexplored potential [17].

The implementation level of methods and tools for supporting sustainability considerations in product development is generally low, possibly due to inadequate practical applicability and incomplete sustainability coverage. One alternative solution is to incorporate sustainability aspects into existing methods and tools that are commonly used in organizations [14].

To effectively tackle sustainability challenges and design products for a more environmentally friendly future, the initial requirement is to train employees with a new perspective that incorporates not only economic considerations but also environmental and social aspects into their daily works [5].

Using tools related to lean thinking can assist in recognizing economic, environmental, and social waste. The search for entirely new methodologies may not be the best solution to enhance the sustainability of products. The primary issue is not the scarcity of methods and tools, but rather their application, and further reflection is needed on how they can aid each aspect of sustainability [10].

The study conducted by K. F. Barcia et al. [21] identifies the frequently used lean six sigma approaches implemented to enhance sustainability. Apart from [21], no other paper states which aspects of sustainability can be influenced by certain lean tools.

Table 2 Authors grouped according to the tools and models analyzed

LPD Tool	Reference
A3	[33], [34], [5]
AHP	[35], [36]
Cradle to cradle (C2C) design	[37]
Design for sustainability (DfS)	[5], [38], [39], [40]
Design of experiments (DOE)	[33], [36]
Functional modelling	[33]
Employee involvement	[41], [21], [42]
Pull & Just-in-time (JIT)	[43], [17], [41], [21], [42], [40]
Kaizen (Continuous Improvement)	[33], [17], [43], [41], [21], [42], [40]
Plan, Do, Check, Act (PDCA)	[43], [17]
Poka Yoke	[43], [17], [40]
Preference set-based design (PSD) / Set based concurrent engineering	[14], [44], [38]
Product Development VSM	[43], [17], [41], [33], [38], [36]
Six sigma, QFD	[41], [38], [42], [40], [36], [33]
Standardization, Standardized work	[43], [17], [34], [40]
Trade-off curves	[33], [34]
Visual Management	[43], [17], [40]
5S	[41], [17], [43], [42], [40], [36]
FMEA	[36], [33]

By combining LPD with their lean management approach, organizations have a better chance of considering sustainability in their product development processes. Opportunities for integrating sustainable views into product development arise when sustainability aspects are incorporated into LPD methods and tools that are already utilized by companies on a regular basis. An analysis of the impact of every single LPD tools on individual aspects of

sustainability is lacking. It would also be necessary to examine whether certain aspects can be incorporated into known popular LPD tools to avoid the creation of new methods and tools.

4 CONCLUSION AND FUTURE RESEARCH

Theoretically, our study results contribute to advancing the literature in the field of LPD and sustainability. The study provided important information on relationship between LPD tools and sustainability aspects.

This manuscript helps foster the evolving debate of integrating the principle of lean and sustainable in product development and contributes to a deeper understanding of their relationship from the literature's examination. In conclusion, the research results provide valuable information for companies to make informed decisions. The continuous improvement teams of companies can utilize this research to identify the most commonly used lean methods and tools that have a positive impact on sustainability.

This study establishes a theoretical basis for further investigations on these topics, highlighting opportunities for future research. It also gives researchers and managers interested in enhancing sustainability the chance to obtain valuable insights on the types of LPD methods and tools that could be utilized. It points out the most utilised LPD tools and sustainability aspects across the economic, social, and environmental dimensions.

To provide directions for future research and taking into account the gaps found in their research, authors have identified the directions for future research:

1) Measurement of the impact of every single LPD tool on sustainability aspects
2) Investigate how can a sustainability aspect be integrated into LPD tools which are already used in companies daily

This would have practical implications for LPD as it would support the recognition of the tools and prioritise their influence so that improvement plans for sustainability could be made.

Like any research, this research has its own limitations, and it's crucial to recognise them. Firstly, this study's search process only covered two major database, which means that some relevant information might have been overlooked. Conducting a more thorough investigation and gathering data from additional databases could have resulted in a more comprehensive analysis of the connections between lean and sustainability.

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