MANAGEMENT PRACTICES FOR SUSTAINABLE PRODUCT DEVELOPMENT: INSIGHTS FROM A SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

Sustainable Product Development (SPD) has been gaining increased attention in academia, industry, and policy. Over the past three decades, significant progress has been observed in incorporation of environmental issues into the product development process, through the so-called ecodesign management practices. Nevertheless, systematisation of the SPD practices, which simultaneously consider the environmental, social and economic dimensions of sustainability, is still missing. To address this gap, this research aims to identify the existing SPD management practices in the academic literature, with special focus on how sustainability dimensions are currently being considered, their coverage in relation to key knowledge areas for product development and their applicability across the SPD phases. Through a systematic literature review, 362 practices were identified and further classified according to a classification criteria. While environmental considerations are still the most prominent ones, the research highlights the importance of the early stages of product development for SPD, as well as the key knowledge areas which are currently being covered by the practices, such as sustainability evaluation and sustainability improvement.

Keywords: Sustainable product development, Management practice, Ecodesign, Sustainability, Design practice

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1 INTRODUCTION

Over the past decades, Sustainable Product Development (SPD) has been gaining increased attention within manufacturing companies due to the enlarged legal, market and financial pressures driving the development of products with enhanced sustainability performance (Rodrigues *et al.*, 2018). In this research, SPD is defined as the "systematic incorporation of environmental, economic and social considerations into the Product Development Process (PDP) to fulfil the elementary needs of society while improving the environmental and economic performance". Successful SPD has the potential to help companies in minimising the impact throughout the products' lifecycle, as well as to gain and maintain competitive advantage (Clark *et al.*, 2009; Hwang *et al.*, 2013).

Nevertheless, most of the focus (both on literature and practice) has been on the integration of environmental considerations into the PDP, while the social and economic considerations lag behind (Rodrigues *et al.*, 2017). Different terminologies have been used for integrating environmental issues into the PDP (Sheldrick and Rahimifard, 2013), such as green design, ecodesign, Design for the Environment (DfE), environmental design, and ecological design. Ecodesign, for example, aims to minimise environmental impacts of products during its lifecycle, without compromising other requirements such as performance and cost (Johansson, 2002).

Even though many ecodesign guidelines and tools exist, a lack of systematic implementation by companies led to the development of the Ecodesign Maturity Model (EcoM2) (Pigosso *et al.*, 2013), which aimed to support the selection of the most appropriated ecodesign practices through a maturity-based approach. The EcoM2 contains a set of 62 ecodesign management practices (i.e., "practices involved in the management of the product development and related processes") (Pigosso *et al.*, 2014). With a sole focus on ecodesign and the lack of consolidation of recent developments in the field, the applicability of the existing management practices for SPD is questionable.

Hence, this research focuses on the further identification and systematisation of management practices for SPD through a Systematic Literature Review (SLR), as described in Section 2. Section 3 provides an overview of the identified SPD management practices, in relation to three main classification criteria: (1) sustainability dimensions; (2) focus areas; and (3) applicability across the SPD phases. Conclusion and final remarks are presented in Section 5.

2 RESEARCH METHODOLOGY

With a view to address the research aim, a SLR was employed as the main research method for data collection and analysis, based on a protocol developed according to the guidelines proposed by Biolchini et al., (2005).

The focus of the SLR was defined based on the research question: "What are the existing management practices for SPD in literature?". To identify the relevant papers, two groups (blocks) of keywords were identified to formulate the search string: (i) "Sustainable Product Development" and related synonyms, and (ii) "Practices" and related synonyms.

The most representative synonyms were selected iteratively based on the background literature, resulting in the following search string: (("sustainable product development" OR "sustainable product design" OR "ecodesign" OR "eco-design" OR "design for sustainability" OR "green design" OR "environmental product development" OR "environmental design" OR "design for environment" OR "environmentally conscious design") AND ("practi?e*" OR "tool*" OR "method*" OR "framework*" OR "technique*" OR "approach*" OR "initiative*" OR "strateg*" OR "guideline*" OR "model*")).

Scopus was the selected scientific database to perform the search due to its relevance for the topic, and for being considered one of the most comprehensive and reliable scientific databases (Dahmani *et al.*, 2021). The search resulted in the identification of 564 unique articles. The selection of the most relevant articles was carried out based on four filters according to the defined inclusion and exclusion criteria (Table 1). In total, 169 unique articles were selected for the detailed analysis and data extraction.

The selected articles were reviewed in depth for the identification of the SPD management practices, as defined by the EcoM2 (Pigosso *et al.*, 2013). The extraction of the SPD practices was carried out from the selected articles, using Mendeley Reference Manager. All the data were recorded in Microsoft Excel worksheet for further analysis.

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Table 1. Summary of the SLR protocol

Element	Description
Filters used	Filter 1: Article title, Keywords Filter 2: Abstract Filter 3: Introduction, Conclusion Filter 4: Full text
Inclusion criteria	Type of study: Scientific articles (incl. journal and conference articles) published after 2010 The study must have identified SPD practice/s The study must focus on manufacturing companies The study must focus on PDP
Exclusion criteria	Duplicates, Articles not in English, Nonrelated fields (Medicine, Pharmacy, Nursing, Psychology etc.)

The identified SPD practices were classified according to three main classification criteria (Table 2): (i) sustainability dimensions, (ii) PDP phases (based on the phases defined by ISO/TR 14062:2002(E), (2002) and (iii) key focus areas (inductive areas that emerged from the analysis of the selected papers). During the identification of key focus areas, the authors' judgements were noted as the reasons or "focus" for applying the practices. The 13 focus areas were identified as recurring focus areas while referring the literature, which were identified as key focus areas. "Other" category includes the focus areas with less occurrences yet identified in the literature as focus of SPD practices.

Table 2. Classification criteria

Classification criteria	Contents
Sustainability dimensions	Environmental, Economic, Social
PDP phases	Planning, Conceptual design, Detailed design, Testing & prototype, Production & market launch, Product review
Key focus area	Legislative, Sustainability evaluation, Customer requirement, Innovation, Sustainability improvement, Knowledge, Production cost, Quality, Company image, Risk, Trade-off decision support, Social commitment, Stakeholders, Other

Finally, an initial descriptive analysis was conducted to characterise the identified SPD management practices, including an analysis of the evolution of the literature landscape over the past decade (section 3.1), an overview of the addressed sustainability dimensions (section 3.2), the distribution of the practices across the PDP phases (section 3.3) and key focus areas (section 3.4), as well as a cross analysis of the key focus areas covered across the PDP stages (section 3.5).

3 RESULTS AND DISCUSSION

3.1 Literature landscape

The historical development of the articles describing SPD practices is presented in Figure 1. A growing concern of the subject area is observed over the years, from 2010 to 2022, with a significant increased focus from 2017 to 2019, with up to 20 papers published in 2018 (and a high predominance of conference articles). Despite the slight decline in the publication of conference papers observed in 2020 and 2021, the total amount of journal articles remained roughly constant, which indicates the continued importance and relevance of the field. The reason for the decline in recent years might be attributed to the intense development of corelated areas, such as circular product design.

Over the past years, academic literature has made a substantial progress towards developing key concepts such as circular product strategies, synergies between environmental management and manufacturing trends etc (Diaz Tena *et al.*, 2021). Most of this research, however, is based on the foundations for ecodesign and sustainable design. From the identified practices, 80% are tested while 20% are still in the conceptual stage. It was further noticed that none of the practices are yet consolidated, i.e., widely applied during PDP.

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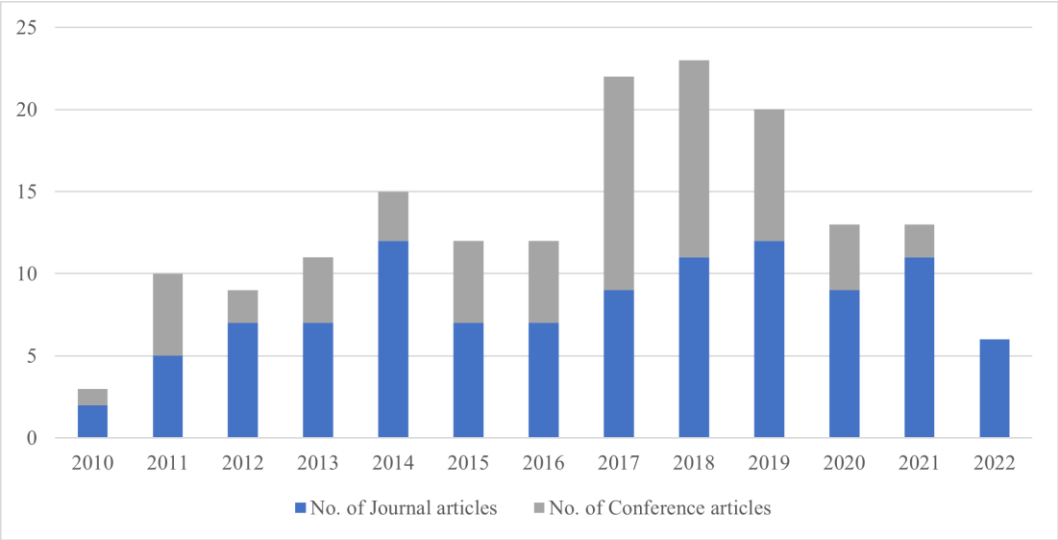

Figure 1. Evolution of SPD-related publications over time
(2022 covers articles published until March, when the search was carried out)

3.2 Sustainability dimensions addressed by the SPD management practices

The research resulted in the identification of 362 management practices for SPD. All the identified SPD practices were classified based on the three pillars of sustainability (i.e., environmental, social and economic) to visualise the distribution of practices (Figure 2).

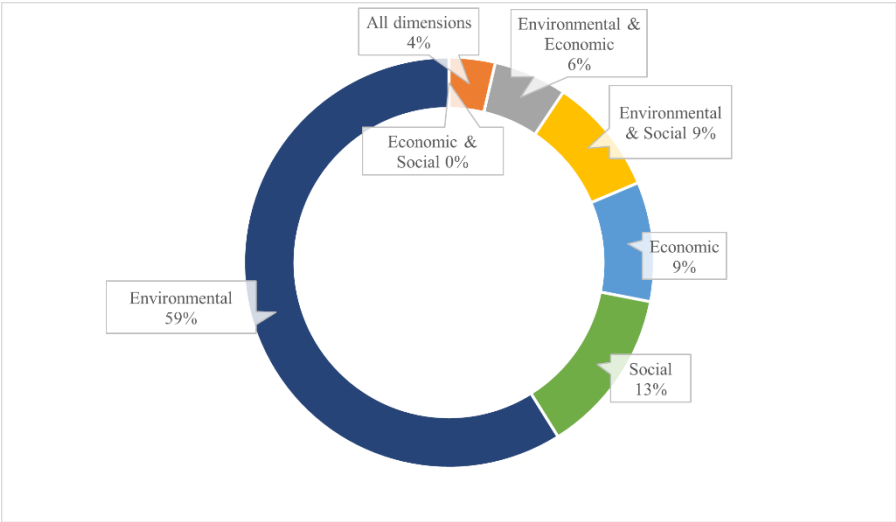

Figure 2. Distribution of SPD practices in three sustainability dimensions

The results revealed that the majority of the SPD practices (59%) solely address the environmental pillar (e.g., *"Identify the environmental hotspots and determine effective interventions"* (Manzardo *et al.*, 2021)). While 13% of the practices address social concerns (e.g., *"Clarify and widen the scope of current sustainability policy, and other steering documents, to include a more comprehensive social commitment"* (Watz and Hallstedt, 2022)), the economic pillar is addressed by only 9% of practices (e.g., *"Effective prioritization process to ensure the projects that will deliver the greatest business value and environmental benefit"* (Dekoninck *et al.*, 2016)).
It is also observed that 9% of the practices address environmental and social pillars in combination (e.g., *"Include a holistic socio-ecological sustainability perspective and make sustainability risks tangible for the product developers"* (Schulte and Knuts, 2022)) and 6% of the practices address both environmental and economic pillars (e.g., *"Alignment of successive incremental eco-design improvements into viable development paths toward the development of circular and sustainable business models"* (Mendoza *et al.*, 2017)). Only 4% of the total practices address all 3 dimensions together (e.g., *"Include strategic sustainability perspective to the concept of product portfolio"*

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(Villamil *et al.*, 2021)). Furthermore, none of the practices address economic and social pillars simultaneously.
The trend towards a significant higher consideration of environmental issues when compared to social and economic considerations can hinder incorporation of socio-economic requirements during product development and must be focus on future research to ensure that SPD is in fact contributing to the three dimensions of sustainability.

3.3 Distribution of the SPD management practices across the PDP phases

The identified SPD practices were classified according to the six PDP phases, as defined by ISO/TR 14062:2002(E). The definition of the key activities for each one of the phases is further described in Table 3.

Table 3. Generic PDP phases (based on ISO/TR 14062:2002(E))

PDP phases	Key activities
Planning	Formulation of product requirements by analysing the external (*customer needs and expectations, market situation, environmental requirements, legal requirements*) and internal (*financial resources, data availability, manufacturing capacity*) factors influencing the planned product.
Conceptual design	Realise requirements for the product, based on the insights gained in the planning stage and obtain an overview of the significant aspects over the product life cycle. Iterative evaluation of the design concepts against each other and in comparison with existing solutions on the market.
Detailed design	Further develop product concept(s) to meet the product design specification and to specify the product. Involve different participants (designers, engineers, production planners, marketing personnel etc.) to work together in refining the design concept to meet the design specification.
Testing & prototype	Check the detailed design against environmental targets and other specifications by assessing environmental performance of the product. The information gained during this stage can be used for communicating the environmental aspects of the product prior to and during marketing.
Production & market launch	Communicate information on the product's features and benefits to encourage customers to purchase or procure the product.
Product review	Obtain feedback from customers and other stakeholders. Conduct a review to find out whether the expectations of the organization, customers, etc. have been met.

The spread of the identified SPD management practices across the PDP phases is presented in Figure 3. The majority of the SPD practices (62%) are meant to be applied during the planning stage. An example of a practice to be applied in this phase is: "*Systematically identify and assess sustainability risks a*nd strategically *manage them" (*Schulte and Knuts, 2022*).*

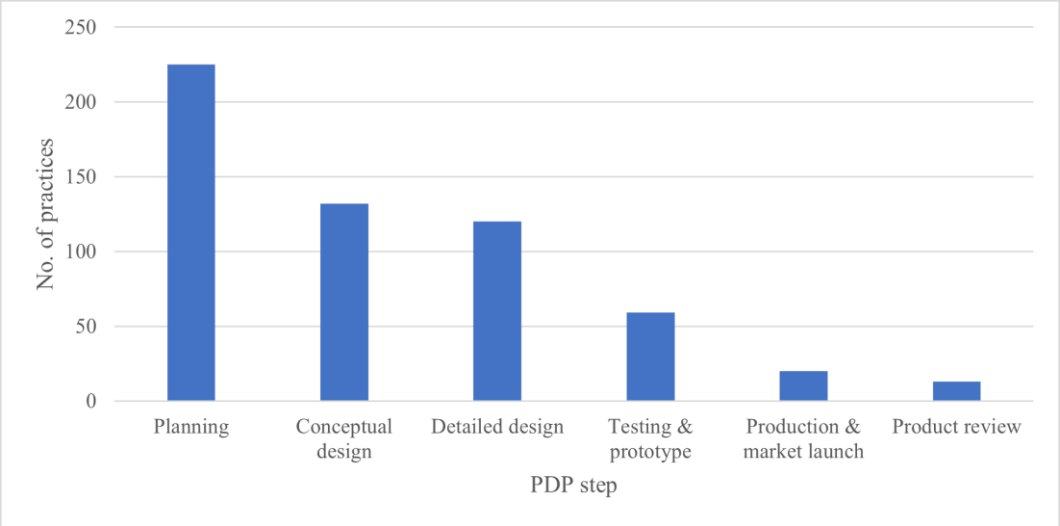

Figure 3. Application of SPD practices across the PDP phases

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The second, third and fourth highest occurrence of practices was observed during Conceptual design, Detailed design and Testing & prototyping, accounting for 37%, 33% and 16% respectively. During Conceptual design, product requirements are realised into alternative concepts, which also requires several management practices (e.g., *"Use a baseline product as a reference to verify the improvement of the environmental performance of the new product"* (Manzardo *et al.*, 2021)). Detailed design deals with developing the selected concept further, so to meet the product design specifications. The developed concept may lead to the collection of refined data which enables the identification of possible environmental impacts across the entire lifecycle. An example of a practice applied in this phase is: *"Selection of the best product version"* (Dostatni, 2018).

The results illustrate the higher intensity of application of SPD practices during the early stages of product development, rationalizing the importance of early integration of sustainability considerations into the PDP. Most environmental impacts are decided during the early phases of product development (McAloone *et al.*, 2009).

Testing & prototyping provides an opportunity to check the formulated detailed design against environmental requirements identified during the Planning stage. An example of a SPD practice carried out in this stage is: *"Identify the environmental hotspots and determine effective interventions"* (Manzardo *et al.*, 2021). Production and market launch accounts for 6% of the practices, where the communication of the environmental performance of the products to customers is planned. One of the SPD practices applied at this phase is *"Include internal and external communication strategy and initiatives in ecodesign"* (Brones and Monteiro De Carvalho, 2015). The final phase of the PDP is Product review, where revisions are undertaken based on the feedback obtained from stakeholders. It is observed that the least number of practices (4%) were applied in this stage, proving that many practices are applied toward the initial stages of PDP.

3.4 Distribution of the SPD management practices across key focus areas

One important criterion used for the classification of the identified SPD practices in this research was the key focus area of the practice. Initially, few focus areas were identified deductively based on the background literature (e.g.,, legislation, sustainability evaluation, and customer requirements). All the other focus areas emerged inductively during the analysis of the selected papers and SPD practices. Altogether, 13 focus areas were identified based on a recurrence analysis (Table 4). The focus areas which had a lower recurrence were categorised as "Other".

Table 4. Description of key focus areas

Focus area	Description
Legislation & regulation	Requirements which must be met by companies to comply with sustainability requirements (either voluntary or mandatory) ((European Union, n.d.))
Sustainability evaluation	An appraisal methodology to assess environmental, social and economic aspects which supports decision making (Sala *et al.*, 2015)
Customer requirement	Specifications or features of a product or service that are deemed necessary by customers
Innovation	Application of new ideas to produce better outcomes (Australian National Audit Office., 2009)
Sustainability improvement	Enhance sustainability performance and minimize environmental impacts of the product/process
Knowledge	Sustainability skills and information acquired through education and experience
Production cost	Expenses incurred for the entire PDP or part of the process to create a new product
Quality	Characteristics of products defined and measured according to the requirements of the company
Company image	Perception of customers on the company that can build/enhance loyalty and credibility
Risk	Uncertain environmental, social, or economic event or condition that can occur causing significant negative impact on the company
Trade-off decision support	Information or guidance that can support to deal with trade-offs in sustainability related decision-making process in the company

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Social commitment	Consider social impacts of the corporate actions taken in improving businesses and act upon them (Hutchins and Sutherland, 2008)
Stakeholders	Individual or group of people that has the interest in the company and outcomes of its actions
Other	Additional focus areas that are not accounted in the above categories (e.g., Employee motivation, Market retention, Recycling)

The distribution of the SPD practices based on the key focus areas is illustrated in Figure 4. The highest number of SPD practices (171 practices) were focused on Sustainability evaluation. An example for a practice which focuses on sustainability evaluation is: *"Analysis of design alternatives and environmental performance of the product"* (Margallo *et al.*, 2021). Sustainability evaluation is a common task to assess the effectiveness of actions taken towards incorporating sustainability into the PDP and is considered to be the main cornerstone for SPD practices in manufacturing companies.

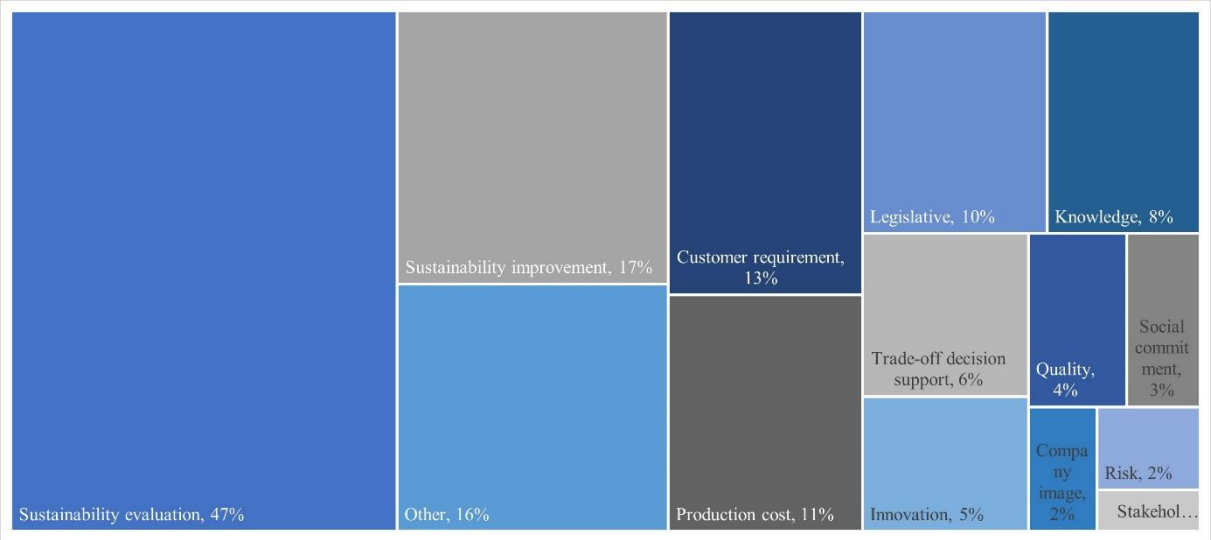

Figure 4. Distribution of SPD practices based on their key focus area/s

The second highest focus was given to Sustainability improvement (63 practices). An example of a practice focused on sustainability improvement is *"Generate design targets and alternatives for enhancing sustainability"* (Zhang *et al.*, 2020). It is observed that practices clustered within this focus area leads to the identification of the design alternatives focused on the hotpots in order to minimise the environmental, social or economic impacts over the lifecycle of the product.

Customer requirements, Production cost, Knowledge and Legislation accounted for 47, 39, 35 and 28 SPD practices, respectively. An example of a practice focused on Customer requirements is *"Comprehensive analysis of customer requirement for the product"* (Zong *et al.*, 2019). Based on a study conducted with Swedish product development and manufacturing companies, it is understood that comparatively higher consideration of customer requirements can support companies in incorporating sustainability into the product design based on their preferences (Watz and Hallstedt, 2022). *"Provide sustainability training to all employees"* (Watz and Hallstedt, 2022) and *"Identification of required improvements for environmental certification through gap analysis"* (Pigosso and McAloone, 2015) are examples of SPD practices focused on Knowledge and Legislation, respectively, which are some key areas to consider for having a successful integration of sustainability considerations into the PDP.

The focus areas Trade-off decision support, Innovation and Quality were less pronounced, and only 56 practices were collectively identified for these focus areas. The SPD practice *"Establish routine which encourages decision board or designers to engage sustainability experts in requirement discussions"* (Watz and Hallstedt, 2022) is one example to highlight the Trade-off decision support, showing how the SPD process can be prioritised of a company amongst the routine activities. Innovation and Quality are two focus areas that were not directly expressed in the SPD practices. An example of practice which focus on innovation and quality is: *"Create more service-oriented business models"* (Schulte and Hallstedt, 2018).

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3.5 Cross-analysis of the key focus areas across the PDP stages

All the SPD practices were analysed based on the key focus areas and corresponding PDP phases. The frequency of SPD practice occurrence within a given focus areas is calculated for each one of the six PDP phases (Table 5). The colour gradient illustrates the intensity of SPD practice occurrence. Green shades indicate higher occurrences whereas red shades indicate lower occurrences.

Table 5. Distribution of SPD practices across PDP stages based on key focus areas

PDP Step	Focus area													
	Sustainability evaluation	Other	Sustainability improvement	Customer requirement	Production cost	Knowledge	Legislation & regulation	Innovation	Trade-off decision support	Social commitment	Quality	Company image	Risk	Stakeholders
Planning	29%	13%	13%	8%	6%	9%	6%	3%	5%	3%	2%	1%	2%	1%
Conceptual design	39%	10%	13%	8%	8%	4%	5%	4%	3%	1%	2%	1%	2%	0%
Detailed design	39%	9%	13%	9%	8%	2%	8%	2%	3%	1%	3%	2%	1%	0%
Testing & prototype	41%	11%	14%	7%	10%	2%	9%	1%	0%	2%	0%	2%	0%	0%
Production & market launch	27%	27%	17%	3%	10%	3%	7%	0%	0%	3%	0%	3%	0%	0%
Product review	25%	13%	13%	6%	13%	6%	13%	0%	0%	13%	0%	0%	0%	0%

Sustainability evaluation is the focus area with the highest occurrence of SPD practices being applied throughout all the PDP phases. Conceptual design, Detailed design and Testing & prototyping are the stages where sustainability evaluation is mostly considered, but sustainability evaluation is also carried out up until the very end of product development (including Production & market launch), so to ensure that the enhanced sustainability performance of the developed products is properly communicated to key customers and stakeholders. Furthermore, Sustainability improvement was also a dominant focus area across all the PDP phases. Production cost, Customer requirements and Legislation were also noticeably present across all the PDP phases, highlighting the importance of such areas to ensure that the product does not only have a superior sustainability performance, but remains still competitive in the market on the basis of the traditional requirements for product development (such as quality and cost). Production cost has been particularly relevant for SPD practices applied during Testing & prototyping, Production & market launch and Product review.

Social commitment has had a particularly high occurrence during the Product review phase, possibly due to a direct consideration of users' feedback during this stage for the redesign of the product to better fulfil their needs. Even though knowledge and expertise of the design team is particularly relevant during the Detailed design, a lower focus was observed for sustainability knowledge at this stage, which raises a question related to the relevant knowledge necessary for typical activities during this stage, such as material selection (Pahl et al., 2007). It was also interesting to notice that Quality of the product and Stakeholders were less focused when applying SPD practices. The reasons behind such observations are not clear with this literature study and actual company situations need to be analysed for further clarification. Finally, it is observed that Risk has a slightly higher consideration during the early stages of the PDP, so that the efforts taken for risk mitigation have a higher success outcome. This analysis illustrates how the focus of SPD practices are differentiated along the PDP, but the applicability in manufacturing companies is not yet known.

4 CONCLUSION

The systematic literature review resulted in the identification of 362 SPD practices, which were further analysed according to the considered sustainability dimensions, their applicability across different phases of the PDP, and key focus areas. In summary, the key findings of the study are:

- Most of the SPD practices are still focused on the environmental aspects, with an incipient development of social and economic aspects. A recent trend was observed for a stronger incorporation of social aspects., but more research must be carried out for the true consideration of sustainability.

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- Most of the identified SPD practices are applied during the early stages of the PDP (i.e., "Planning" and "Conceptual design"), corroborating the fact that the largest opportunities for the development of sustainable products are in the incorporation of sustainability concerns during the early stages of product development.
- A large majority of SPD practices are focused on Sustainability evaluation and Sustainability improvement, with a similar occurrence across all the PDP phases. SPD practices within these two focus areas support the definition of requirements, selection of alternatives, and trade-off decisions, potentially leading to a higher effectiveness of actions taken towards incorporating sustainability.

This research enlightens the understanding of the state-of-the-art of SPD management practices, and establishes the foundation for exploring how these practices support companies to achieve their overarching sustainability goals through product development. Future research will be focused on the further consolidation of the identified SPD practices to eliminate overlaps across the practices, leading to more in-depth analyses and the identification of their contribution towards the development of more sustainable products.

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