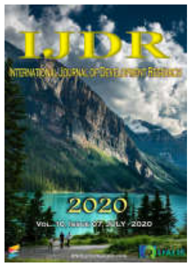
ISSN: 2230-9926

Available online at http://www.journalijdr.com

IJDR

International Journal of Development Research
Vol. 10, Issue, 07, pp. 37537-37548, July, 2020
https://doi.org/10.37118/ijdr.19299.07.2020



RESEARCH ARTICLE OPEN ACCESS

A MATURITY MODEL FOR SUSTAINABILITY IN PRODUCT DEVELOPMENT

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ARTICLE INFO

Article History:
Received 28th April, 2020
Received in revised form
20th May, 2020
Accepted 1st June, 2020
Published online 24th July, 2020

Key Words:
Product development,
Sustainability,
Maturity model,
Evaluation scale,1.

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ABSTRACT

Incorporating business strategies and supporting long-term view for companies is a challenge. In order to help companies to move towards a sustainable business agenda, this article proposes a model to evaluate maturity in terms of sustainability in product development from the perspective of eco-efficiency and eco-effectiveness. The model was developed using the Design Research method. An initial conceptual model was developed based on a literature study. This interactive process resulted in 42 items, a maturity scale, which affords to distinguish the options in the scale. Both were developed, validated by specialists from different countries, and pre-tested. The maturity model was constructed over the categories strategic orientation, design, development process, socio-environmental aspects, and business results. The model includes a questionnaire and a maturity scale that support the application and interpretation of the data collection survey. Additionally, a conceptual maturity and sustainability matrix is presented to facilitate differentiating results among the proposed categories. It supports determining how mature manufacturing organizations are and helps them address sustainability efforts and actions in product development, as part of their organizational strategy.

Citation: ***Lütkemeyer Filho, Mário Gilberto , Vaccaro, Guilherme Luís Roehe, Modolo, Regina Célia Espinosa and Moraes, Carlos Alberto Mendes.*** "A maturity model for sustainability in product development*", International Journal of Development Research*, 10, (07), 37537-37548.

INTRODUCTION

Sustainability in business processes requires internal and external self-consciousnessfrom the organization. Even though external elements collapse due to diverse perspectives in business (Boons and Lüdeke-Freund, 2013), they restrict and influence decision-making and help the organization grow in the perception of shareholder value (Baumann *et al*., 2002; Nidumolu *et al*., 2009; Gmelin and Seuring, 2014), since focusing solely on the shareholder is no longer viable. In order to develop sustainable operations, products, and services, organizations have to understand how their own existence impacts on processes, materials, resources, and strategic orientation (UNEP, 2007; Mont and Bleischwitz, 2007). This affords to identify alternatives to the dialectic between the short-term view, or competitiveness (Plouffe *et al*., 2011), and the long-term view, i.e., sustainability (Dyllick and Hockerts, 2002; Waage, 2007). Sustainability issues allow referring back to the so-called Porter Hypothesis (Porter and Van Der Linde, 1995a),which falls short from playing an essential part in the system of socioeconomic equations that rule corporate strategy. Companies compelled to adopt sustain-ability practices are not clear on how to measure their level of adherence to existing approaches, since the quest for sustainability may demand a changein their mindset on products and processes (Nidumolu *et al*., 2009).If the concept of sustainable development is not new and implies wisdom and maturity (Kellner-Stoll, 2004), why do shortfalls take place to organizations adopting sustainable practices, in line with future generation needs (WCED, 1987)? From the perspective of this research, sustainable maturity is a combination of the progressive steps to be adopted in PD (SEI, 2010; Rozenfeld *et al*., 2009), different thinking, and the implementation of the stages of sustainability (Nidumolu *et al*., 2009; Willard, 2005). To complement this point of view, a sustainably mature company is the one that promotes sustainable development by contributing with social, environmental, and economic aspects (Hart and Milstein, 2003).Previous studies have presented the guidelines to integrate sustainability into PD (Hallstedt*et al*., 2010; May *et al*., 2012), and investigated the integration of sustainability in PD from the perspective of environmental demands by underlying importance of investing in sustainable businesses and products (Gmelin and Seuring, 2014; Bocken *et al*., 2014). These studies also suggested business models for sustainability (Boons andLüdeke-Freund, 2013),and proposed a maturity model framework from ecodesign (Pigosso *et al*., 2013). However, none of these studies have proposed a maturity model in sustainabilityfrom the PD standpoint and based on the concepts of eco-efficiency and eco-effectiveness. Eco-efficiency is defined as a management philosophy that aims to improve environmental performance by reducing resource-intensiveness along a life cycle (WBCSD, 2000). In turn, eco-effectiveness is the ability to sustain a cyclic and closed flow of materials in industrial systems, similarly to natural ecosystems (Braungart and McDonough, 2002). Those seminal concepts can be comprehended as relative environmental sustainability (eco-efficiency) and absolute sustainability (Cradle-to-Cradle), in which they not only challenge eco-efficiency but also provide a future view on how to increase the positive impact of designed products rather than reducing (eco-effectiveness) (Bjorn and Hauschild, 2012).

The comparative analysis of eco-efficiency and eco-effectiveness is recent, and few studies have addressed it. Previous investigations have explored the differences between eco-efficiency and eco-effectiveness in e-commerce (Abukhader, 2007), and discussed eco-efficient and eco-effective concepts. In this sense, it may be said that the concepts of eco-efficiency and of eco-effectiveness may improve each other mutually (Bjorn and Hauschild, 2012). A few years ago, Young and Tilley (2006) published a paper proposing a business model moving further from eco- and socio-efficiency. Other elements that lend strength to this notion are the poor capabilities of designers and engineers in designing sustainable products (May *et al*., 2012), the low effort of designers in terms of the pre-requisites for sustainability in product design (Finster *et al*., 2002).

Decisions taken during the design phase involve materials, performance, functionality, durability, maintenance, cost, and environmental performance (Luttropp and Lagerstedt, 2006),affecting the firm's internal structures (Byggeth and Hochschorner, 2006; Short *et al*., 2012; Boons and Lüdeke-Freund, 2013) as well as bridging design approaches with future need for resources (Hallstedt *et al*., 2013). Although companies ought to address a long-term sustainability view with product and services strategies and innovative solutions (Gaziulusoy *et al*., 2012), there is a paradigmatic polarity in terms of implementing business strategies and solutions based on eco-efficiency rather than eco-effectiveness (Braungart *et al*., 2007; Burnett *et al*., 2011; Bjorn and Hauschild, 2012). In this paper, the authors consider both as complementary concepts. Although the WCED (1987) definition of sustainability addresses a well-discussed but challenging point to companies in terms of achieving a balanced, dynamic production and consumption system,current levels of generated waste may be overcome when organizations rethink their business and production operations in light of the legislation. In Brazil, this theme is considered in the National Policy for Solid Waste (PNRS) (Brasil, 2010).

The extendedmanufacturer's responsibility, called take-back responsibility andobserved in Europe and the USA, reflects previous studies and ideas (Porter and Van Der Linde, 1995b; Siegel, 2009). Investment in clean processes generate financial returns, though it also adds intangible assets, such as the access to new consumer markets, risk reduction, and greater competitiveness (Porter and Van Der Linde, 1995b; Bleischwitz, 2010). The underlying premise is that costs are reduced due to the increase in productivity over the costs of extraction of natural resources, to the decrease of waste in processes, and to the conversion of what was considered a waste into something that has value and is marketable (Porter and Van Der Linde, 1995a; WBCSD, 2000). However, this requires organizations to reach a maturity status concerning several aspects of the development of sustainable products.

The arguments above point to the importance of diagnosing maturity in a firm concerning the concepts of adopting sustainability in PD. Under such perspective, this study proposes a maturity model to assess the use of sustainability in PD. It is a strategy-oriented business process and has central importance in the economic success of an organization (Gmelin and Seuring, 2014). This maturity model was built based on a literature review. A questionnaire is presented, followed by a maturity scale based on SEI (2010), Rozenfeld *et al*. (2010), Willard (2005), and Nidumolu *et al*. (2009). Since the Likert scale may not be effective when one single term may be interpreted in a variety of ways (Malmbrandt and Ahlström, 2012), the model is described through a conceptual maturity and sustainability matrix (CMSM), presented in section 4. Finally, the model proposed is compared with the maturity model proposed by Hynds *et al*. (2014), due to the scarcity of maturity models to evaluate sustainability in PD in the literature. For this, five main dimensions were identified and used to develop this work: strategic orientation, design, development process, socio-environmental aspects, and financial results. These dimensions derive from an initial conceptual proposal, which supports the model that will be presented in the following sections.

METHODOLOGY

The method used was based on Design Research. According to Mason (2006) and Vaishnavi and Kuechler (2009), this approach affords to develop tools that help understand and change behavior of an information system or a given reality. The result of this process is the proposal of an artifact, or, in other words, the maturity model to be adopted for sustainability in PD. The building steps of the maturity model are summarizedin Figure 1. Initially, a literature review was carried out to outline a theoretical framework. Scientific databases were accessed (Science Direct, Scopus, EbscoHost, Dart Europe, and Scielo) in order to find papers using the keywords 'product development', 'eco-efficiency', 'eco-effectiveness', and 'maturity model'. Nineteen relevant papers associated were identified from databases. Due to the scarcity of papers associated with sustainable maturity models, several papers connected with sustainable approaches, such as ecodesign, design for environment (DfE), design for sustainability (DfS), cradle-to-cradle (C2C), circular economy (CE), in addition to books and a few seminal and historical publications associated with sustainability were included in the research. After a review of those publications, the initial conceptual model was proposed. Fifteen sustainability specialists from Europe, Asia, South America, and North America were invited to evaluate the model. After two contact attempts, six experts accepted the invitation. All participants have solid experience in sustainability (academic and research experience, consulting, government projects) evidenced by international publications or professional activities. Apart from adding diversity and incorporating a sense of collaboration for enhancing the model, learning from different opinions would contribute a robust model. The role of the experts consisted of evaluating the model, identifying aspects that require improvement, and supporting the construction of a refined second conceptual model. These professionals participated throughone-to-one recorded semi-structured interviews (Flick, 2004) conducted online or face-to-face appointments.

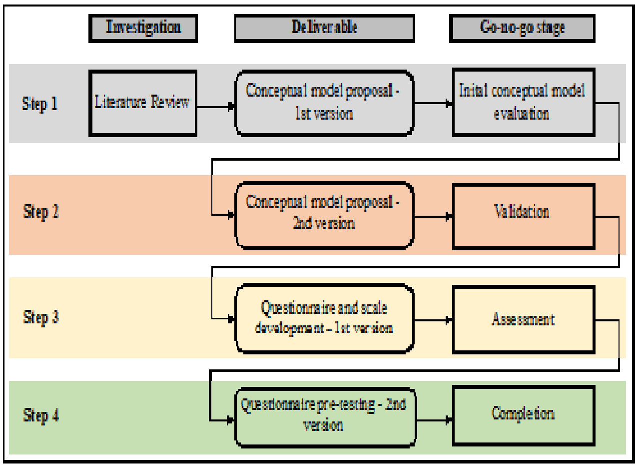

Figure 1. Steps adopted to develop and validate the model.

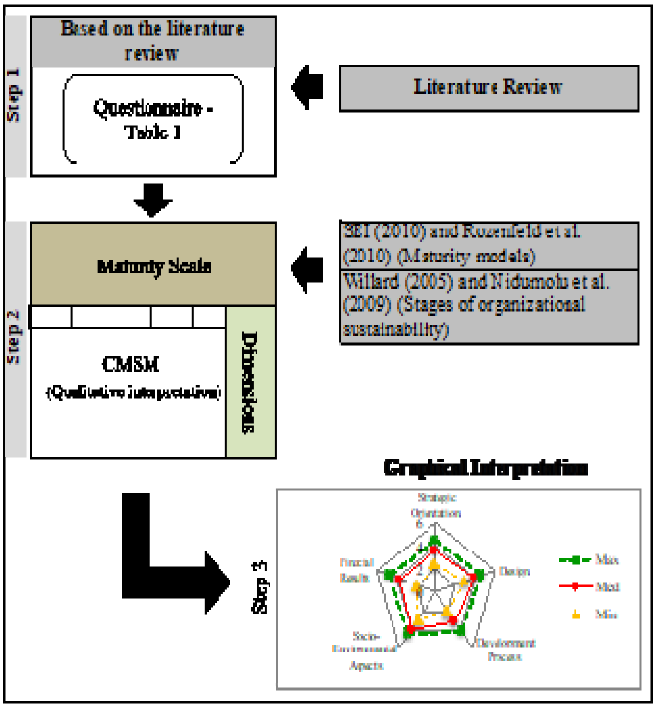

Figure 2. Maturity model schemes, which supports the interpretation of the maturity model

Topics of interest were evoked during interviews in order to drive consistency and a systematic inquiring process, such as: (i) the relationship between the proposed dimension and associated constructs; (ii) the relationship between the proposed constructs and PD; (iii) the importance of proposed constructs when it comes to implementing sustainable strategies in companies; (iv) the main challenges and barriers to inserting the dimensions and constructs in PD, and (v) the level of agreement about the theoretical model as well as opportunities for improvement.The contributions were transcribed and analyzed based on the content analysis techniques (Bardin, 1995). A refined version of the second model was submitted to the same six specialists. One provided contributionthat includedsmall changesin the model; therefore, it was assumed that the refined conceptual sounded clear to the other specialists, since no response was provided by them. At the end, the second conceptual model was compiled, now with dimension and constructs, resulting in a conceptual framework. The following step was the generation of an initial version of the questionnaire. It was conceived with the dimensions strategic orientation, design, development process, socio-environmental aspects, and financial results,totalizing 16 constructs and 42items, which aim to operationalize these constructs and support the proposals suggested.

The first version of the questionnaire was submitted to five academic researchers on quantitative analysis, engineering, and sustainability, who did not participate in the group of six specialists aforementioned. At this point the objective was to assess and gather a pool of contributions andto validate the questionnaire structure and its items. Their suggestions were incorporated in a second version of a questionnaire, which was adjusted and improved. Finally, the second version (Table 2)was adjusted for the pre-testing. The pre-testing consisted of sending 18 questionnaires to manufacturing companies in Brazil (automotive supplier manufacturing industries and automotive companies), which should be answered by PD leaders or managers, followed by phone calls to confirm an answer. In total,10 questionnaireswere answered. Cronbach's alpha results indicated the outcomes, as follows: (i) strategic orientation = 0.91; (ii) design = 0.92; (iii) development process = 0.89; (iv) socio-environmental aspects = 0.92,and (vi) financial results = 0.72. Reliable questionnaires indicate results associated with internal reliability between 0.7 and 0.9 alpha values (Hair *et al*., 2005; Malhotra, 2012).

Results above 0.9 may indicate"inflation of response" when questionnaires are long. In the present situation, the questionnaire contains 42items, meaning that it is long, but valid for application. The maturity scale is presented in section 4 (Table 4). The type of scale used was multi-item, or verbal label, which is appropriate for maturity levels, since it allows interpreting what is requested (Hair *et al*., 2005). According to Godson (2002 apud Malmbrandt and Alström, 2012), maturity levels are directed to practitioners and describe the distinct levels and progressive degrees of a determined application. In a context evaluation and adoption of lean thought, Malmbrandt and Alström (2012) understand that the Likert scale has both advantages and disadvantages in complex contexts or when several interpretations are possible. Due to descriptive analysis reasons, the labels are replaced for a scale that ranged from 1 to 5 (Hair *et al*., 2005), in order to represent pooled results. The Friedman test was also used to analyze the data obtained in the pre-test. The results indicate that calculated significance was below 1.0 ($\alpha < 0.10$), meaning that the scale may discriminate answers. Also, the experts who contributed to improve the questionnaire validated the scale. Malhotra (2012) underlines the fact that the validation of a construct is complex and difficult (convergent, discriminating, and nomological validation). Put simply, a high reliability result indicates the relationship between reliability and validity.

DISCUSSION AND ANALYSIS

Conceptual framework and model: The modelis composed of five dimensions: strategic orientation; design; development process; socio-environmental process; and financial results.

Table 1. Questionnaire build from the literature review (conceptual framework)

DIMENSION	CONSTRUCT	ITEMS
Strategic orientation	Life cycle perspective	1) Questions associated with the impacts of product life cycle (manufacture, use, and post-use) are included in discussions at strategic level.
		2) Reduction of waste and losses (in manufacture, use, and post-use) is used to direct the analysis of existing opportunities.
		3) Workers, suppliers, customers, and society in general are directed and encouraged to use natural resources sustainably.
		4) Workers, suppliers, customers, and society in general are directed and encouraged to use products sustainably.
	Business model	5) Sustainable services solutions are part of the organization's business strategies.
		6) The organization prefers to develop suppliers and procure components locally.
	Technological development management	7) The development and use of sustainable products, services or technologies is a priority in the organization.
		8) Technology is used as a means to mitigate environmental and social problems in the long term.
		9) Innovative solutions are implemented in product development.
	Technical capabilities	10) The capabilities required by project teams in the development of sustainable products are identified and evaluated.
		11) Professionals with technical capabilities and knowledge about social and environmental aspects are preferred for product development.
Design	Materials	12) The environmental impact caused by chemicals is a determining factor in the selection of materials.
		13) Cost is not the main variable to influence the selection of materials.
		14) The organization has clear selection criterion for materials, based on the mitigation of environmental impacts (in manufacture, use, and post-use).
	Energy	15) Energy efficiency (in manufacture, use, and post-use) is a determining factor in the selection of materials.
		16) The organization develops products and processes focused on alternative and clean energy sources.
		17) The organization uses one technique or procedure to select less energy-intensive materials.
		18) There is a defined process in place to assess energy consumption of products in the use and post-use stages.
	Simultaneous engineering	19) Simultaneous engineering is used in product design and development.
		20) Simultaneous engineering is important in the development of sustainable products.
Development process	Upcycling	21) The use of reusable materials is a priority in the organization.
		22) Clearly defined processes are in place to convert waste in raw materials in the different stages of the product's life cycle.
	Cyclic flow	23) The organization uses collaboration processes with other firms to reuse materials in product post-use.
		24) The processes and products are designed to allow recyclability of materials.
		25) Metrics are used to assess the amount of materials and products reused, recovered, and recycled.
	Reduce, reuse e recycle	26) In product development, the organization uses techniques conceived to reduce the quantity of materials used.
		27) The organization uses processes that facilitate reuse or recycling of products and materials.
		28) Suppliers are involved in the implementation of the reverse cycle (reverse logistics).
Socio-environmental aspects	Eco-equity	29) The practices in the organization are based on socio-environmental sustainability in the long term.
	Culture and ethics	30) The organization has and publicizes clear ethics guidelines.
		31) The values publicizes by the firm include ethics aspects in product development.
	Regulation	32) The organization has the ISO 14001 certification.
		33) The organization works with partners in the supply chain in the search for continuous process improvement.
		34) The organization applies directives according to the National Policy for Solid Waste (PNRS).
		35) The organization uses the compliance of environmental standards as a means to gain advantage over competitors.
	Natural capital	36) The organization has clear goals to reduce consumption of natural resources.
		37) The organization directs the development of new products as a way to reduce socio-environmental problems.
		38) Sustainability of the business depends on investment in the availability of natural resources in the future.
Financial Results	Eco-efficiency &	39) The organization uses indicators aiming to maximize economic returns per raw material unit and to mitigate environmental impact.
	Eco-effectiveness	40) The organization's financial results is impacted positively by eco-effective processes and practices.
	Profitability	41) Profitability is based on sustainable products.
		42) The organization aims at markets even if consumers and regulations are demanding regarding sustainability.

Table 2. Maturity Models (a) from SEI (2010) and Rozenfeld *et al*. (2010); and Organizational maturity models (b) from Willard (2005) and Nidumolu *et al*. (2009).

Maturity models		Stages of organizational maturity	
Level 1	Initial (S) Basic (R)	Stage 1	Pre-Compliance (W) Viewing compliance as opportunity (N)
Level 2	Managed (S) Intermediary (R)	Stage 2	Compliance (W) Making value chain sustainable (N)
Level 3	Defined (S) Results are measured (R)	Stage 3	Beyond compliance (W) Designing sustainable products and services (N)
Level 4	Quantitatively Managed (S) Corrections are controlled (R)	Stage 4	Integrated strategy (W) Developing new business models (N)
Level 5	Optimizing (S) Continuous Improvement (R)	Stage 5	Purpose and passion (W) Creating next practice platforms (N)
	S=SEI (2010), R=Rozenfeld et al. (2010)		W=Willard (2005), N=Nidumolu et al. (2009)

Table 3. Maturity scale (MS) and the conceptual maturity and sustainability matrix (CMSM).

MS	The organization does not know and does not use the concept	The organization knows but does not use the concept	The organization has initial projects or a pilot project that include this concept	The organization implemented this concept partially or in some areas	The organization implemented this concept fully or completely in all areas
	1	2	3	4	5
Conceptual maturity and sustainability matrix (CMSM) / Dimensions			Qualitative interpretation		
Strategic Orientation	No action to promote sustainable solutions as well as investing in technical capabilities Business models focused on production of goods	No action to promote sustainable solutions as well as investing in technical capabilities Business models designed based on production of goods.	Limited actions to development of sustainable solutions Business models are considered but limited by costs, capabilities allocated are defined based on technical issues.	Strategic orientation for developing sustainable solutions Sustainable business models and technologies are implemented but limited by costs as well as allocation of adequate capabilities.	Sustainable processes and products driven by strategic orientation Sustainable business models, innovative technologies and capabilities are defined according to the long-term view.
Design	Energy consumption and material and energy requirements are not known There is no notion about simultaneous engineering Designs and produces in a non-structured pattern.	Awareness that selecting energy efficient may provide sustainable gains No systematic process to select less energy- intensive materials Simultaneous engineering is not adopted in design activities.	The use of less energy-intensive materials is stimulated The material choices are made in a non-systematic way and limited by cost Simultaneous engineering is used, but the process is not structured.	Materials and energy required by processes and products are designed to meet sustainability principles Best practices are not fully implemented, and simultaneous engineering is used in some areas.	Materials and energy required by processes and products are systematically used in to meet sustainability principles Simultaneous engineering is employed to develop sustainable products and promote competitiveness.
Development Process	No business processes, or initiatives to reduce waste and maintain materials in closed loops Environmental impacts caused by organizational activities are not considered	There is awareness of the impact caused and of the volumes of waste generated throughout the life cycle No processes and routines to maintain materials in a closed loop.	The organization aims to add value to waste, but based non-systematic processes There are a few process to reduce waste generation and keep materials in a closed loop No systematic reverse cycle processes in the supply chain.	Business processes to minimize waste and keep materials in closed loop are under implementation Organization adds value to waste in some occasions as supply chain is partially prepared to meet reverse cycle processes.	Business processes are systematically designed to reduce waste and maintain materials in the closed loop The organization aims to add value to waste as supply chain is prepared to reuse materials and products, which are monitored by metrics.
Socio-environmental Aspects	Socio-environmental aspects are neglected No notion of business impact of natural capital availability Laws and regulations are ignored.	Socio-environmental aspects are known, though there is neither culture nor actions in place to meet these requirements. No professional expertise to determine the requirements of standards and regulations are meet.	Socio-environmental aspects are understood, but not fully Initiatives to create a culture and the awareness about the consumption of natural resources and the risks associated Laws and regulations are understood in a few functions of the organization.	Socio-environmental aspects are understood, respected and best practices are quite implemented Ethical and eco-equity aspects are implemented Laws and regulations are followed, but the organization does not go beyond what is required.	Socio-environmental aspects are understood, and requirements are met Investments in the minimization of waste are seen as business opportunities and carried out beyond legal requirements There is the culture and the perception that business continuity depends on the availability of natural resources.
Financial Results	Eco-efficiency and its contribution in organizational results is not considered. No investment in sustainable processes and products, or to increase competitiveness.	Reduction of materials and in the implementation of clean processes is not an immediate requirement No initiatives in place to maximize the use of resources and economic returns.	A few eco-efficient processes are implemented, metrics are sporadically used to evaluate the use of materials and of energy Understanding that investing in sustainable products stimulates competitiveness is limited and restricted by the short-term returns.	There is an effort to implement processes that reduce waste, which is essential for competitiveness Best practices and metrics are adopted in some functions, and some efforts are focused on long-term returns.	Systematic investments are made in clean processes to increase competitiveness and economic returns, based on the awareness about sustainability Efforts are directed to long-term returns.

Table 4. Comparative matrix of the maturity model proposed in the present study and the model proposed by Hynds *et al*. (2014).

			The proposed maturity model															
			Dimensions															
			Strategic Orientation				Design			Development Process				Socio-environmental Aspects			Financial Results	
			Life cycle perspective	Development management	Business models	Technical capabilities	Materials	Energy	Simultaneous engineering	Upcycling	Cyclic flow	Reduce, reuse and recycle	Eco-equity	Culture and ethics	Regulation	Natural capital	Profitability	Eco-efficiency and Eco-effectiveness
Maturity model proposed by Hynds et al. (2014)	Strategy dimensions	Corporate Sustainability Policy	•	•		•									•		•	•
		Overall Sustainability Strategy	•											•			•	•
		Government Policy & Regulation	•		•										•			
		Impact of Trends	•		•		•	•		•	•	•	•	•		•		
		Supply Chain (CSR)	•		•											•		
		Green labeling	•		•										•			•
		Sustainability Design for Environment (DfE)	•	•	•	•	•	•					•	•			•	•
	Design tools dimensions	Specifications/Customer Insights		•	•	•	•	•	•			•						
		Life Cycle Assessment (LCA) Process					•	•	•	•		•				•		
		DfE–Material and Part Selection					•	•	•	•	•	•	•		•	•		
		DfE–Supply Chain					•	•			•	•	•	•		•		
		DfE–Manufacturing Impact						•				•	•	•		•		
		DfE–Use Phase Impact					•	•	•	•	•	•	•	•	•	•		
		DfE–End of Life Impact						•		•	•	•	•	•	•	•		

Each dimension is associated to a proposition and further addressed in the survey instrument.

Dimension 1: Strategic orientation: Due to the complexity of PD processes, structured and systematic processes have to unfold according to the organization's strategic orientation (Rozenfeld *et al*., 2010; Gmelin and Seuring, 2014). Organizations are demanded to take actions to meet economic, social, and environmental aspects in business policies and processes (Brent and Labuschagne, 2007). However, it may lead to the impression that short-term improvements are enough also in the long-term scenario (Braungart and McDonough, 2002). It has been stated that European organizations are slowly introducing the perspective of life cycle and eco-efficiency in decision-making processes (Mont and Bleischwitz, 2007). Meanwhile, Dyllick and Hockerts (2002) emphasize that strategies influence eco-efficiency directly, adding value to the organization. Later, Young and Tilley (2006) presented a discussion of corporate business agenda surpassing the notion of eco-efficiency and addressing elements of sustainability based on eco-effectiveness. In 1995, Porter and Van Der Linde (1995a) addressed the opportunities in massive investments in reducing the consumption of natural resources. The opportunities in competition in order to subvert the linear mindset of natural resource consumption should be stimulated and promoted, in order to guarantee operational compliance by firms (Hawken *et al*., 2007), which, in turn, requires specific actions towards reducing product consumption (Chick and Charter, 1995) and focus on use (Braungart *et al*., 2007; Bocken *et al*., 2014). This notion demands technical capabilities in the development of sustainable products and processes requiring products to be developed using more comprehensive systems, compared to the present ones (Johansson, 2002; May *et al*., 2012; Manzini and Vezolli, 2008). Innovation and new technologies are influenced by the design of sustainable business models at system level, significantly reducing demand for natural resources and creating social benefit and ultimately rearranging business processes (Bocken *et al*., 2014). Due to the importance of the strategic orientation in organizational business processes, mainly in the scope of the development of new products, the following proposal is presented:

P1: *Sustainably mature organizations have a strategic orientation toward product development aligned with business models, life cycle perspective, technological management and technical capabilities.*

Dimension 2: Design: In general, design and development of new products are closely connected (Lagerstedt, 2003). Design is part of the early stage of product development (Ulricht and Eppinger, 2008) and essential to determine impacts over product lifecycle (Waage, 2007; Hallstedt *et al*, 2013). In the early stages of PD, there is more flexibility to define product characteristics. This freedom springs from the needs of markets and customers, which are converted in engineering parameters (Lagerstedt, 2003; Luttropp and Lagerstedt, 2006; Fiksel, 2009). Decisions made at this stage determine the environmental impacts throughout a product's life cycle at around 80% (Lagerstedt, 2003), consolidate 70% of the costs of the manufacture stage, use and post-use of products (Waage, 2007), and result from the impacts caused by material flow (consumption of material, entropy, and emissions) resulting from the three stages above (Wagner and Enzler, 2006). In this study, the design approach adopted is that developed by Fiksel (2009), i.e., minimizing the use of material and energy during a product's life cycle. As a consequence, it is essential to limit the generation of entropy (Spangenberg *et al*., 2012).

One of the techniques used to evaluate environmental impacts is life cycle analysis (LCA) (Höjer *et al*., 2008; Birch *et al*., 2012). The methodology, which was consolidated in the early 1990's, was adopted and standardized following the standard 14044:2006. Due to the complexity and the time required in its application, this approach is seen as controversial by organizations, which aim to use a simplified form of LCA so as to speed up the development of information needed in decision making during the early stages of design (Fiksel, 2009). For sustainable development to become a viable alternative, the choices made during design are essential to determine lifespan and productivity of natural resources and materials, to minimize the need for unused raw materials (Andersen, 2007; Ashby, 2009; The Ellen MacArthur Foundation, 2012), and to guarantee the feasibility of materials in a closed loop (Jacques, 2011; The Ellen MacArthur Foundation, 2012).Braungart *et al*. (2007) claim that materials have to be designed and kept in closed loops throughout several life cycles. As for energy, the relationship with materials is intrinsic and direct. The amount of energy available in a material resource in terms of products is called exergy. The more energy extracted from materials using processes, the better. Based on this premise, Ayres (2001) and Fiksel (2009) believe that energy efficiency in materials and processes is one of the drivers to reduce carbon footprint. Growing extraction of ores and industrial activities have increased the generation of waste and CO_2 levels, global warming, environmental and social impacts (Andersen, 2007). Energy availability grows as raw materials and natural resources are converted into scale volumes (Mackay, 2009).Actions devised to increase energy efficiency using design of products and processes become relevant, even when the theoretical and practical limitations are taken into consideration (Kiperstook *et al*., 2002). This standpoint lends strength to the perspective developed by Luttropp and Lagerstedt (2006), who point to the relevance of increasing energy efficiency during production, use, and post-use, under the label of eco-design. Another important element in the design stage is simultaneous engineering. According to May *et al*. (2012), management of activities using this approach influences time-to-market of products. As for the development of sustainable products, it affords greater freedom in the early stages of the process, when it is possible to assess, quantify and change engineering specifications (May *et al*., 2012; Luttropp and Lagerstedt, 2006; Ulricht and Eppinger, 2008). Due to the gap stressed by May *et al*. (2012) and the efficacy of a development process based on choices (Lagerstedt, 2003; Luttropp and Lagerstedt, 2006), this construct is used as a means to evaluate the level of compliance of the organizations monitored. Therefore, to explain the organizational reality within the outlined boundaries, the following proposal is presented:

P2: *Systematic approaches and concurrent engineering in the phase of product design have been used to reduce environmental impacts of material and energy in sustainably mature organizations.*

Dimension 3: Development Process: A development process starts with the customer needs, which translate as engineering specifications. Then, a given product is manufactured and marketed in systematic, structured ways (Ulricht and Eppinger, 2008). For Baumann *et al*. (2002), the development process is linked with internal organizational processes, in a scenario that mixes competition and collaboration throughout this relationship.PD is efficient when waste is reduced overall, not exclusively in the production environment (Morgan and Liker, 2008; Brent and Labuschagne, 2007; Dangelico and Pujari, 2010). For Hart and Milstein (2003), organizations take guidance from four basic motivators when they require to implement profitable and environmentally correct processes: (i) the reduction of consumption of raw materials; (ii) transparency in business (for stakeholders); (iii) the intensive use of clean technologies; and (iv) the efforts to develop less polluting and resource-intensive processes (Kiperstook *et al*., 2002; Bleischwitz, 2010; Stahel, 2010). In this sense, upcycling can be described as reusing a material without downgrading the quality and composition of the material for its next use. It allows products considered waste to be reinserted in the productive chain, adding value and improving return on investment for firms and society, requiring all players in the chain to engage in collaborative and synergic processes (Braungart and McDonough, 2013; Hallstedt *et al.*, 2013). In other words, upcycling champions do not pinpoint the limitations inherent to the phenomenon. The 3 R's rule (reduce, reuse, and recycle) is used to operationalize PD in terms of sustainability. This approach affords not only to use the right amounts of materials in development processes, but also to increase reuse and recycle rates throughout product life cycle (Karlsson and Luttropp, 2006; Bleischwitz, 2010). Jackson (2009) draws attention to the fact that reuse, repair, and remanufacture are preferred options to recycling, since they afford to postpone disposal on landfills and reduce the demand for virgin raw materials. Evidence indicates that the adoption of the 3 R's in development processes requires appropriate regulation. In Brazil,organizations have to adapt to the National Policy for Solid Waste (PNRS) (Brasil, 2010) in order to meet the legal requirements defined and that stipulate minimization, reduction and maintenance goals for materials in closed loops. These regulations also define responsibilities of manufacturers. This scenario poses challenges for organizations,since they have to redesign processes and products based on current technologies and thus direct sustainable development from the holistic perspective (Hart and Milstein, 2003; Nascimento *et al.*, 2008), highlighting existing gaps in empirical research in to the direction of developing sustainable solutionsKautto (2006). Based on this discussion, the development process is a key element in the scope of sustainability. Literature and regulations addressing the reduction of natural resource use and waste generation represent interesting opportunities for organizations. Nevertheless, they do not determine whether the context presented is important for the implementation of cyclic processes and the creation of a culture based on sustainable development in PD. In order to reveal the relationship between the elements exposed, the following proposal is put forward:

P3:*Sustainably mature organizations adopt development processes that promote the closed loop of materials.*

Dimension 4: Socio-environmental aspects

Socio-environmental aspects, as proposed by the World Business Council of Sustainable Development (WBCSD, 2000), aim to integrate ethics into corporate practice and, concomitantly, improve quality of life of workers and of the community. A few decades ago Meadows *et al.* (1972) discussed the future of population growthcomparing to pollution and consumption of natural resources, envisioning the planet' collapse within 100 years. Initially, the scientific community met this idea with skepticism, though there is the understanding that it is necessary to reduce pollution and the use of natural resources considering the planet's capacity to absorb these impacts (Braungart and McDonough, 2002; Dyllick and Hockerts, 2002; Young and Tiley, 2006). In this sense, industrial systems are interconnected with the generation of new demands and consumer markets, which have direct impact on the extraction of raw materials, short product life cycles, obsolescence, and return of materials to the ecosphere (Ashby, 2009). How can we treat what is generated and avoid pollution? How can we prevent harm to human health and to the natural environment? Lifset and Graedel (2002) discussed these topics pointing to the flow and the volume of materials in the technosphere. Industrial systems are not isolated entities; on the contrary, they interact with environmental and social systems and are directly accountable for the results of such interactions (Chertow, 2000). For Manzini and Vezolli (2008), the proposal of sustainable systems requires the combination of products and services, henceforth called product-service, which includes different degrees of technical and sociocultural innovation. Thus, connecting people and ecology means taking a full perspective of sustainability, and remains a challenge requiring further research (Hallstedt *et al.*, 2013).The eco-equity principle is associated with the access to natural resources. The way in which organizations do business now determines how this access will take place in the future. Organizations have to act responsibly in order to maturate resource consumption patterns and guarantee that the future generations may enjoy what nature makes available (Hart and Milstein, 2003; Willard, 2005).

Firms have to use raw materials appropriately, increasing productivity but minimizing emission and disposal rates (Hart and Milstein, 2003). The adoption of ethical standards becomes more complex in times when global organizations need to adapt operations to cultural aspects in different regions. As a result, perceived behavior patterns help improve competitiveness (Nascimento *et al.*, 2008). These operation patterns are aligned to corporate social responsibility (CSR) practices, which mean doing business from the ethical standpoint while contributing to economic development and improving social standard life of families,in a process of communication with stakeholders based on transparency principles (Willard, 2005; Nascimento *et al.*, 2008; Forbes, 2013; Larkin, 2013). For Porter and Van Der Linde (1995b), stricter regulations promote innovation in the effort to meet emission and waste disposal requirements. In this sense, regulation requires the reconfiguration of processes and products, which represents an increase in expenditure inherent to the innovation moves implemented. The authors also suggest that the impact of investment and of compliance to regulations diminishes with time because of the trade-offs with innovation potential and the positive impact on financial results. In the same line, governments and societies must engage in comprehensive discussions about how to change the current financial mindset (Larkin, 2013). Campbell *et al.* (2012) underline this standpoint and say that organizations move towards a change in the way economic, social, and environmental results are communicated to stakeholders.

In a study about the integration of sustainability in the development of new products carried out with Italian firms, Kerga *et al.* (2011) observed that investments in sustainability in new product development only occur because of national legal requirements. The authors also report the firms' skepticismover the real financial benefits that may result from such investments. This evidence underlines the relevance of the notions presented by Hallstedt *et al.* (2010), when the authors show that short-term goals are prioritized against long-term ones due to the lack of a notion of sustainability and of managerial support. The struggle between investing in innovation and the disbelief in the improvement of competitiveness based on environmental results is considered one of the main challenges organizations have to respond to (Porter and Van Der Linde, 1995a). It has been proposed that the increase of resources' productivity through investment in innovation brings about systemic benefits (Porter and Van Der Linde, 1995a; Nidumolu *et al.*, 2009). This position clashes with the current mindset, according to which costs are normally allocated in order to keep inefficient and underused products generated in non-optimized processes (Porter and

Van Der Linde, 1995a). A change in mindset may require new sustainability practices in the future, in spite of the disbelief in serving markets where customers are not willing to pay more for improvements in times of crisis (Nidumolu *et al*., 2009). In order understand the relationship between paradigm and socio-environmental benefits, the following proposal is put forward:

P4:*Sustainably mature organizations associate product development with compliance to eco-equity, cultural and ethical values, regulation and natural capital.*

Dimension 5: Financial Results: Today, the economic result is the motto that preconizes increase in profitability, in market share, and in competitiveness. The focus on economic sustainability is confined to the short-term perspective (Dyllick and Hockerts, 2002). This point of view is maintained by Pérez-Calderón *et al*. (2011), according to whom a traditional publication group believes that investing in environmental management and sustainable solutions disrupts competitiveness and profitability. As a reaction to the need for change and for the development of a new perception of improving the use and the availability of natural resources, the concept of eco-efficiency was presented by the WBCSD (2000).

The organization states that, from the business perspective, eco-efficiency is essential as a means to secure positive results, since it maximizes addedvalue by efficiently using resources and boosting economic advantage. It may be adopted in any organizational area, from marketing to production so that adding value to business tends to be seen as an increase in productivity in the use of natural resources. Reducing waste represents an opportunity to improve profitability (Hawken *et al*., 2007; Porter and Van Der Linde, 1995b), since it unveils the potential for making profit hidden behind it (Stahel, 2010).

The use of resources may be controlled using indicators, as suggested by the WBCSD (2000): (i) the reduction in material, product, and service intensity, (ii) the reduction in the energy used in products and services, (iii) the reduction in the emissions of toxic compounds, (iv) the incentive to recycling, (v) the maximization of the use of renewable resources, (vi) the increase in product durability, and (vii) the increase in the intensity of use of products and services. These indicators represent a way to monitor the impacts caused by activities in business and the influence they have in the organization's financial performance. For Porter and Van Der Linde (1995b), profitability is the consequence of overcoming the static paradigm according to which investment in clean technologies increases operational costs. On the contrary, this investment reduces treatment of waste and pollution, and brings benefits such as opportunities to invest more in innovation, in technologies and in strategies so as to reduce risks to business (Nidumolu *et al*., 2009).

However, there is the dilemma between investing lookingforward to the long term and affecting the benefits in the short term (win-win), which represents an obstacle that has to be overcome (Porter and Van Der Linde, 1995a; Hahn *et al*., 2010). One of the possible advantages in becoming a "green" organization is the access to more restricted markets, based on the offer of sustainable products (Porter and Van Der Linde, 1995a; Nascimento *et al*., 2008; Nidumolu *et al*., 2009). An answer to these questions is partly offered by Pérez-Calderón *et al*. (2011), when their research identified the positive relationship between less polluting (eco-efficient) companies and their economic and financial performance. On the other hand, Burnett *et al*. (2011) published a study linking corporate value and eco-effective management, though the authors could not report positive results only by projecting future accounting ones, not in the current account period. Considering that the win-win process concerning sustainable development of organizations has not yet consolidated and that the results are focused on a behavior pattern confined to the short-term perspective, the following proposal is presented:

P5: *Sustainably mature organizations associate their financial results to eco-efficient and eco-effective actions addressed via PD.*

The maturity model conception: This research introduces a maturity model based on eco-efficiency and eco-effectiveness discussions. It reinforces the paper scope amplitude and delivers schemes of the maturity model as well as outlines the interpretation (Figure 1), which may guide users to apply the model. It is important to point to the similarities between our proposal and the research done by Hallstedt *et al*. (2013). The four key elements highlighted in their study, namely organization level, process level, roles/people, and tools are somehow associated within the dimensions strategic orientation, design and development processes, and, to some extent, with socio-environmental aspects. The existing points in common between the aforementioned papers only indicate the relevance of the challenges associated with the implementation of sustainable strategies. This maturity model is directed to PD managers from manufacturing companies, since they provide guidance about company direction to their teams (Hallstedt *et al*., 2010). They are the ones who should answer the questionnaire, which can be analyzed using statistical techniques, allowingthe identification of the maturity level for every single construct, a general overview of maturity levels on a dimension basis, in addition to discussing the main opportunities to implement sustainably business solutions. Once the maturity profile is identified, it will enable companies to compare the results obtained with the proposals stated at the end of the literature review for every single dimension.

The maturity model is interpreted according to a combination of the following three steps:

- Step one includes: The detailed literature review, which sustained the dimension and constructs definition. Then the questionnaire was developed, based on the literature review and validated according to appropriate procedures.
- Step two comprises: The maturity scale definition that is based on maturity models (SEI, 2010 and Rozenfeld *et al*., 2010) and sustainability organizational models (Willard, 2005 and Nidumolu *et al*., 2009) as well as development of the Conceptual Matrix in Sustainable Maturity (CMSM) in the light of literature.The CMSM allows understanding qualitatively the integration level of sustainability into PD by means of reading the labels in the scale (upper horizontal bar) compared with the model dimensions (vertical column on the right). Besides, the central part of the matrix allows the interaction between maturity results and literature, based on distinction criteria for each dimension and labeling (Table 3).

- Step three includes: When the instrument is applied in companies, the results obtained will afford to analyze the maturity level for organizations in regard to every single dimension and construct. Radar graphs can be built in order to improve the visual interpretation of gaps and strengths in terms of implementation level of sustainability. The CMSM will then provide guidance to implement sustainable strategies into PD.

The integration across dimensions and constructs in the theoretical framework supports the construction of the maturity model proposed. PD is composed by generic elements (Ulricht and Eppinger, 2008), like pre-development, development, and post-development (Rozenfeld *et al*., 2010). As previously mentioned, the objective of proposing a maturity model is to find out whether manufacturing companies adhere to sustainable concepts, by means of diagnosing a sustainable profile and evaluating the compliance levelwith the principles of future generation needs (WCED, 1987).Finally, it supported the construction of the conceptual framework and the questionnaire (Table 1). Regarding the proposal of the maturity scale in PD, it should be observed that stages are arranged in continuous and sequential levels, from the first stage to the higher maturity stage. The maturity scale was developed based on the software Integrated Product Development Maturity Model (IPD-CMMI), Software Engineering Institute (SEI, 2010) and the Maturity Model for Product Development Process (PDP), by Rozenfeld *et al.* (2010) (Table 2a). Those models cover exclusively product and process development, not addressing sustainability. For this reason, studies about organizational sustainability published by Willard (2005) and Nidumolu *et al.* (2009) (Table 2b) were the references chosen to be adapted to the maturity model.

The maturity scale is composed by 5 levels/labels (top of Table 3): (i) The organization does not know and does not use the concept; (ii) the organization knows but does not use the concept, (iii) the organization has initial projects or a pilot project that include this concept; (iv)the organization implemented this concept partially or in some areas;and (v)the organization implemented this concept fully or completely in all areas. Those levels intend to identify in a categorical manner how deep sustainability concepts are employed in product development environments. In addition to the maturity scale, a conceptual maturity and sustainability matrix (CMSM) was developed (Table 3). The intention is to translate the meaning of maturity level qualitativelyconsidering the model to beimplemented in PD departments in manufacturing organizations. The outcomes from this process should reveal strengths and gaps andwould determine a set of actions to support improving sustainability levels in a company.

Although maturity scales are discussed in the literature, as presented before, maturity models regarding sustainability and PD are still a subject of incipient research. This may be attributed to the complexity of the topic, thus leading to another complex subject of research (Boons and Freund-Lüdeke, 2013; Hallstedt *et al*., 2013). Nevertheless, Hynds *et al.* (2014) presented a proposal covering the same subject as discussed in the present paper. A comparison between both models (Table 4) indicates similarities (marked cells) as well as differences among the selected dimensions of representing sustainability in PD. The gray area indicates a zone of convergent views: the constructs associated with the dimensions strategic orientation, socio-environmental aspects, and financial results agree with the strategic dimensions proposed by Hynds *et al.* (2014); and the dimensions design, development process, and socio-environmental aspects are related with the dimension project tools (DfE). Nevertheless, each model has its own labeling method,while the maturity model developed by Hynds *et al.* (2014) focuses on environmental sustainability for product definition, which is a limited standpoint, if compared to the present proposal. Occasional relationships are observed between design and development process and the dimension impact of trends. This condition is established in light of the adequacy and of the flexibilization of determined macro-environment trends. In the design for environment (DfE), sustainability acts directly on materials and energy. In this sense, the relationship between these elements is important.Specifications and customer desires directly interfere in the management of technological development, that is, they afford to evaluate whether the organization's technological elements can deliver what the customer desires or new business models are required for that purpose. As for technical specifications, it is assumed that the organization has to adapt its staff to the notion of meeting customers' needs. Finally, maturity models for the evaluation of sustainability in PD are new and complex fields of study, which is revealed by the paucity of publications on the subject, as mentioned above. The comparative analysis of both models reveals that they share similarities. However, they are not identical, mainly if the social aspects and the reference elements that give support to our model are considered. Therefore, the present study represents a contribution and a complementation to the theme, in the same sense as proposed by Hynds *et al.* (2014),and points to the importance ofmitigating risks by investing in sustainable solutions (Boons and Lüdeke-Freund, 2013).

Conclusion

This research introduces a questionnaire, a maturity scale, and the conceptual maturity and sustainability matrix (CMSM) to be usedby manufacturing companiesin their efforts to improve the communication between departments concerning what is going well and what has to be changed in the future. It was developed based on a literature review and background on eco-efficiency and eco-effectiveness, as there is a dichotomy between both approaches that requires further research in sustainable business. Seeking for external validation, the proposed model was presented to experts and compared to the one developed by Hynds *et al.* (2014), since no other models were found during the review phase.The comparison with that model pointed outsimilarities between strategic dimensions and the dimensions strategic orientation, result, and socio-environmental aspects. It is in the dimension socio-environmental aspects that the models are less similar, since the model developed by Hynds *et al.* (2014) is focused, essentially, on environmental sustainability. The dimensions design, development process, and socio-environmental aspects agree with the dimension design tools (DfE). The results show the relevance of the topic for researchers and organizations and are proof of the consistency and of the alignment of dimensions and constructs suggested by these questions. Few studies have been published about the evaluation of maturity in the adoption of sustainability in PD. In this sense, the model should be applied in a range of manufacturing companies in order to mitigate business and allow open communication through an organization by addressing sustainability as a

competitive driver. Furthermore, application of the maturity model in a range of manufacturing companies, whethersmall, medium or large may reveal that a more flexible maturity model may better adapt to heterogeneous conditions and PD environments. Other than using the maturity model to assess the use of sustainability in PD, perhaps a more in-depth question to be investigated is:what would be the right mindset, processes, and values required to treat sustainability as a priority in organizations? This is a question whose answers will result in significant differencesregardingthe development of sustainable products and processes.
Future research could also develop maturity models built based on eco-efficient approaches as well as maturity models based on eco-effective approaches. Comparing the outcomes of both maturity profiles would help answering if there is a distinction between short-term view (eco-efficiency) and long-term view (eco-effectiveness). As for the model's limitations, it is underlined that, even with the validation by specialists, greater exposure of the model may lead to further improvements and adaptations. Applications are being carried out aiming to find empirical evidence of the model's reach and its discriminating power.

Acknowledgement

The authors acknowledge CNPq (Brazilian National Council for ScientificResearch) for the grants given to some of the authors: Technological Development Research Grants - DT2/CNPq, and Research productivityProductivity Grant PQ2/CNPq (Process 307755-2018-5), and FAPERGS/RS for their financial support and scholarships to this research.

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