An Overview of Smart Product Manufacturing Based on Classic Product Development Processes

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Abstract. The manufacturing landscape of the industry has been changing in recent years with the current disruptive technological advances. The industry 4.0 paradigm goes beyond the adoption of technology. It has accelerated the development of new concepts and methods that influence products and processes, gradually allowing the creation of intelligent products. Although these advances address the integration of Industry 4.0 with the intelligent product development process, the intelligent product concept does not consolidate yet. Likewise, the classical adjustment of product development processes to meet the prospects of developing and manufacturing smart products should be further addressed. This article contextualizes what has been studied about the concept of intelligent products, the intellectual process of product development, and the importance of enabling technologies of Industry 4.0 in the process. The analysis is carried out based on the study of relevant articles that focus on the themes, the concept, and the development of smart products. In addition, the main differences, and necessary adaptations in the classic product development processes about intelligent product development process frameworks are addressed. The study's main result is an overview of the existing gaps within the problematic issues. In addition, a discussion is carried out on the requirements and needs for future construction of the Intelligent Product Development Processes framework.

Keywords: Smart product · Product development process · Industry 4.0 · Problem analysis

1 Introduction

The industrial scenario has changed in recent decades due to successive technological advances; such advances have increasingly led to the development of products and services that include advanced computing platforms, increasingly characterizing them as intelligent or complex products [1, 2]. Smart products can be described as having autonomy, adaptability, multifunctionality, cooperation, and human interaction within

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the scope for which they were produced [3]. The challenge of promoting smart products, driven by global competition, increases the difficulty of determining customer requirements, being increasingly customizable and challenging to meet. This complexity increases effort and execution time in Product Development Process (PDP) [4, 5]. As a way of promoting agility to the PDP, using the enabling technologies of Industry 4.0, studies involving frameworks, methods, and approaches that use these digital tools to make the process smarter are on the rise [6, 7]. In addition, such frameworks aim to promote connectivity, communicability, and diagnostic capability to control throughout the Product Lifecycle Management (PLM) [8].

Although many studies address the applicability of industry 4.0 concepts in different domains, in the PDP, some ideas are considered nebulous and can bring some confusion [9, 10]. To corroborate this statement, the systematic literature review promoted by [3] about the smart product concept concludes that the high study of this concept by different domains has led to a dispersed and uneven body of knowledge. In [11], the authors highlight the need for framework adaptation between classical product development processes and intelligent product development process methods.

According to this context, this paper promotes an analysis and discussion about the concepts of smart products and the smart product development process based on a literature review. Additionally, it addresses the role of enabling technologies of Industry 4.0 around these themes to support the advancement of PDP.

This article is structured as follows: Sect. 2 addresses the problem statement regarding dispersion in the concept of smart products and the main differences between classical product development processes and innovative methodologies related to smart products. Section 3 presents an analysis of related works found after an initial survey of a theoretical framework. Section 4 discusses the main disadvantages and gaps in the associated results. Finally, Sect. 5 concludes and presents perspectives for further research.

2 Problem Statement

Through the study of the term smart products, it was possible to identify several descriptions of this term and generate diverse perspectives. In the survey developed by [12], the concept of a Smart Product is presented as one capable of retaining or storing data about itself. In [13], the authors point to intelligent products as those skilled in making decisions about themselves and establishing transport of information to other products or systems. The dispersion of the smart product concept impacts the agility of the development and production process of products with such characteristics. In addition, it retards the customer's defining the product requirements [13].

The advancement of emergent technologies, allied with industry 4.0, imposed an interaction between all stages of the classic development processes. With the increase in product complexity, the need to promote intelligence in product development became apparent the more it highlights the need for customized manufacturing requirements demanded by the customer [11, 13]. These contexts require agile methods and cheaper processes to launch innovative and technological products [14].

Therefore, this research intends to clarify the concept of smart products, pointing out the evolutions in the existed or conventional product development process. Additionally,

this research aims to understand the new requirements to make the smart product process development process more agile and respect all customer's needs. Figure 1 summarizes all concepts involved in this research to active a Smart Product.

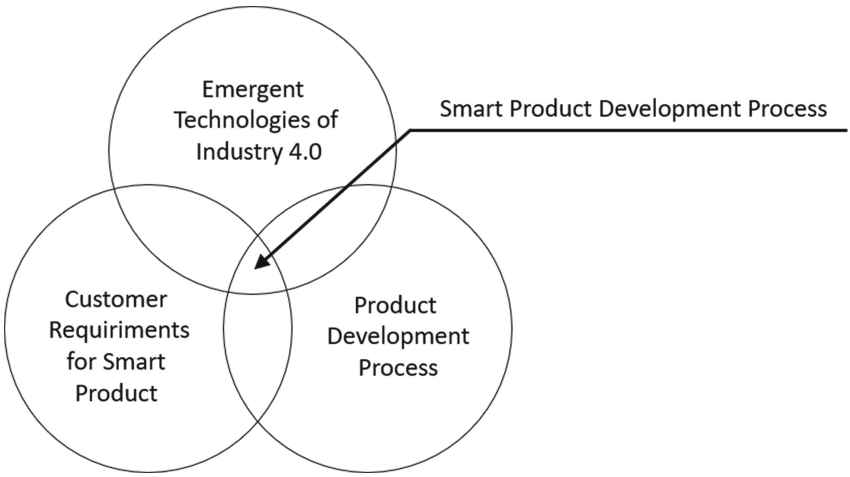

Fig. 1. Faces of the research problem.

Therefore, the starting point will be a previous survey of the theoretical framework considering three main dimensions:

i. The concepts and problems for the design of Smart Product.
ii. The main models of product development processes (Classic Models) and the models of intelligent product development processes.
iii. Industry 4.0 key concepts enable technologies to support smart product development.

This research considers these three dimensions with a discussion that identifies the main related works in this domain. It explores the differences and essential adaptations in the classical methods of product development focused on the agile process and the gaps that can be addressed in this context.

3 Related Works

The methodologies used to build the theoretical framework that supported the discussion about the topics presented were as follows:

i. A survey for articles and papers was carried out in the Scopus database using the following keywords (i) "Smart product development process" and (ii) "Smart products".

ii. The authors used multiple methods to rank the most recent articles and the most relevant research in the domain of this study.
iii. The selected articles were read and classified using four criteria to facilitate the analysis (the criteria will be detailed in Sect. 4 of this document).
iv. Finally, the authors analyzed articles to extract relevant information from the research. In addition, the study is divided into subtopics according to the context of the current research.

The following subsections summarize the extracted information and knowledge from the literature review that supports the discussion presented in Sect. 4. In addition, the subsections were structured according to the three research issues: (i) the Smart product concept issue; (ii) The Smart product development process adaptation issue; and (iii) Emergent Technologies Trends used in the Smart Product issue.

3.1 Smart Product Concept Issue

Although Smart Products are a widely used concept, there is still a need to clarify and centralize a single vision for a better understanding. A preliminary search made it possible to find many archetypes for these terms, and several examples used similar terms to describe different concepts. For example, [15] classify Philips Hue's bright lights, the Amazon Echo, and the self-driving car under the term "smart object," while [16] refers to in-car navigation systems, digital cameras, and cell phones as "smart products." In [17], the authors refer to "intelligent objects. According to [18], the authors consider the term "smart product" as "connected objects," and in [11], the authors introduce the term "internet-connected constituents." In [19], the authors use the term "Digitized artefact," while [18] use the term "smart thing." in a somewhat similar fashion, scholars have also used a variety of terms synonymously. This ambiguity is compounded by the fact that other concepts exhibit overlaps with the smart product but must be clearly distinguished in a conceptual sense.

Furthermore, there is no agreement on the definition and definition of "smart products" criteria. Existing reports are often based on packages of seemingly arbitrary features or features. It was also possible to note that recent research on smart products has focused on their created functions or service offerings and the larger ecosystems in which they operate [3, 19, 21, 22]. In this way, the preliminary study of intelligent products becomes relevant before analyzing and developing process methodologies and producing this new kind of product.

3.2 Smart Product Development Process Adaptation Issue

Within the literature, it was possible to find different perspectives of classic product development. In work developed by [20] are cited: [23] defines it as the process that converts customer needs and requirements into information to produce a product; and [24] defines it as a business process consisting of a set of activities that seek, from the needs of the market and the possibilities and technological constraints. In addition, the author considers companies' competitive strategies and strategies for the product to achieve product specifications.

In more recent research, approaches to intelligent product development were found, such as the study by [2] that compiles the primary studies for more competent production within industry 4.0. Within the research, a shortage of studies sought to adapt the traditional development processes to support intelligent products and services. Because of this, it becomes relevant to deepen the systematic review of the literature to prove this concern and delimit the requirements for such adaptation. Furthermore, in the study carried out by [8], it is already possible to notice an optimization approach for intelligent product service systems proposing a Digital Twin approach as an actuator in optimizing functions of intelligent systems and products.

3.3 Emergent Technologies Trends Used in Smart Product Issue

The industrial scenario has changed in recent decades due to successive technological advances. Industry 4.0, whose concept has been widely discussed by academics and organizations, is a new manufacturing paradigm combining intelligent factories, machines, systems, products, and processes in an integrated network that connects the physical and virtual worlds using Cyber-Physical Systems (CPS) technology. Industry 4.0 involves products and processes and is often related to CPS, the Internet of Things (IoT), and Smart Products, a new industrial approach encompassing future industry developments and technological advances that will increase productivity and business efficiency [24, 26].

Industry 4.0 is focused on creating smart products and processes by transforming conventional factories into smart factories. An intelligent factory environment is characterized by a networked intercommunication between human resources, machines, and objects, such as smart products. Smart products are integrated into the entire manufacturing process and actively support your manufacturing process by autonomously controlling individual production steps. Furthermore, like finished products, smart products are aware of the parameters in which they must be used, providing information on their status throughout their entire life cycle [25].

4 Discussion

This research is working to highlight the issues presented in Sect. 2 to ensure a better understanding of new product development processes and the concept of smart products in the face of the emergence of enabling technologies in industry 4.0. In this way, three dimensions of the problem are proposed to be discussed: the question of the concept of intelligent products, the adaptations in the classic processes of product development that the intelligent development frameworks have been promoting, and the importance of industry 4.0 technologies within this context.

A primary search was conducted where related works were found for each suggested problematic question. After a complete reading, each article was allocated based on the criteria in which it best fit. For a better understanding, subdivisions were made in each main question to guarantee a better perspective of the contribution of each article to this research. The criteria used in the subdivisions are described in Table 1, and the articles/papers classification according to the requirements can be seen in Table 2.

It is possible to notice in Table 1 that, within the selected articles, some themes have been little explored; for example, it is possible to note that few pieces addressed the differences between classic PDPs and intelligent product development processes or established a starting point for companies emerging companies that still use the classical process as a basis [20–22, 28]. In addition, it is possible to notice a high in the research of frameworks using enabling technologies in industry 4.0 aiming at the production of intelligent products but without the allocation of intelligence in the Development process, but with the intelligence focused on the product [17, 25, 27].

Table 1. Subdivisions of discussion questions

Issue	Subdivision	Criteria
Q1: Smart product concept	SP1	The article presents several definitions of smart products
	SP2	The article presents several definitions of smart products and offers as a conclusion a final definition
Q2: Classic PDP models vs. intelligent product development process frameworks	PD1	The article only covers classic product development processes
	PD2	The article only covers intelligent product development frameworks
	PD3	The article covers intelligent product development frameworks based on classic PDP models
Q3: Industry 4.0 enabling technologies	TH1	The article presents topics of enabling technologies of Industry 4.0
	TH2	The articles present topics about enabling technologies of Industry 4.0, linking them with intelligent product development

Another point that was possible to see is the extension of the smart product concept towards an earlier point in the product life cycle, thus leveraging the value-adding in-situ sensing capabilities of the products [28].

On the issue of the concept of smart products, it was possible to highlight the dispersion in the definitions of smart products because few studies centralize or conclude the purposes in a common one. A most detailed explanation was in the systematic literature review developed by [4], which presents four archetypes synonymously to define an intelligent product (digital, responsive, connected, and smart). Such conceptualization can describe the target product's level of complexity and the complexity necessary for its development.

These results represent a preliminary assessment of the issues raised, frameworks, and methodologies found within the literature. However, it is essential to consider that the requirements or conclusions established are not static; variations, advances, and

Table 2. Classification of articles based on the topics studied

Authors and publication year	Q1		Q2			Q3	
	SP1	SP2	PD1	PD2	PD3	TH1	TH2
R. Schmidt, M. Möhring, R.C. Härting et al. (2015) [1]	X					X	X
M.L. Nunes, A.C. Pereira, A.C. Alves (2017) [2]	X	X		X		X	X
S. Raff, D. Wentzel, N. Obwegeser (2020) [3]		X				X	
E. Rauch, P. Dallasega, D.T. Matt (2016) [4]	X				X		
X. Yang, R. Wang, C. Tang, L. Luo, X. Mo (2021) [5]	X			X			
C. Wu, T. Chen, Z. Li, W. Liu (2021) [7]	X				X		X
Z. Chen, X. Ming (2020) [8]	X			X			
M. Touzani, A.A. Charfi, P. Boistel (2018) [9]	X					X	
I.C.L. Ng, S.Y.L. Wakenshaw (2017) [10]	X			X		X	
D.J. Langley, J. van Doorn, I.C.L. Ng, S. Stieglitz, A. Lazovik, A. Boonstra (2021) [24]	X					X	
L. Bieler, T. Gruen, B. Akdeniz et al. (2018) [14]	X			X			
D.L. Hoffman, T.P. Novak (2016) [15]	X			X		X	
D. Beverungen, O. Müller, M. Matzner, J. Mendling, J. vom Brocke (2019) [19]		X				X	
Kärkkäinen et al. (2003) [25]	X			X			X
Kiritsis, D. (2011) [24]		X			X		X
Leitão et al. (2015) [27]		X		X		X	
Meyer et al. (2009) [17]		X		X		X	
Lenz et al. (2020) [28]		X			X		X

improvements in these issues may occur during the evolution of the studies. Within this context, it is necessary to explore more methodologies, research, and concepts to support the proposed questions. The authors consider this approach as the fourth issue to ensure consistency and coherence of system requirements.

5 Conclusions

This research presented a contextualization of adaptation of the traditional processes of product development aiming at the manufacture of intelligent products to guarantee the best use of enabling technologies of Industry 4.0. The issues and concepts addressed in this document are not static; that is, they may undergo changes, updates, or removals during the evolution of research.

To better understand the dimensions of the problem addressed, the authors proposed three key questions to be addressed: the question of the concept of intelligent

products, the classic models of PDP versus the frameworks of intelligent processes of product development, and the importance of enabling technologies of Industry 4.0. in the evolution process of product development. With these questions, relevant articles were searched to determine which gaps were not explored and/or need further research. Within these gaps, the need for standardization or formalization of a concept of smart products was highlighted, in addition to the lack of research on smart product development methodologies that adapt the classic processes of product development and that are focused on promoting intelligence in the process of growth and not just the product.

The continuity of the research should, therefore, promote a systematic review of the literature to deepen and theoretically support the proposed questions to support the development of a framework for adapting the classic processes of product development aimed at the manufacture of intelligent products using enabling technologies of industry 4.0.

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