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LITERATURE REVIEW OF PRODUCT DEVELOPMENT IN MASS PERSONALIZATION AND MASS INDIVIDUALIZATION

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Abstract: *The transitions between the three paradigms of production highlight the shift from mass production to mass personalization and individualization, following the requirement of multiple products, based on modules configurable in different variants. The products have open architecture are developed at the customer requirement and with his involvement. Literature review resulting from the research of the main databases refers to the new product development process, smart product development, open architecture product, in mass individualization and mass personalization. The aim of the research is to develop an open architecture product configurator. Finally, the future of production is presented, consisting of modular and efficient manufacturing systems, which allow one to obtain individualized products in the economic conditions of mass production.*

Key words: *Mass Customization, Mass Personalization, Mass Individualization, Open Architecture Product, Industry 4.0, New Product Development, Smart Product Development, Digital Twin.*

1. INTRODUCTION

Considering the requirements of the clients, in recent years there has been a transition from mass production (MPr) and mass personalization (MP) to mass individualization (MI) [1, 2]. We have found that "complex products with multiple and individualized functions require a high degree of innovation in the design phase and a high degree of flexibility in production" [2].

Although the MP concept has been used for several years, efficient application poses "a great challenge in terms of flexibility and the ability of manufacturers to quickly change variants of manufactured products" [2, 3]. Unlike "customized products, individualized products are aimed at satisfying a single customer" [2]. The customer can change the product design or create new products considering budget and time. The ability to adapt the product design to satisfy Customer Needs (CN) is important in the manufacture of individualized products [2].

Product reconfiguration consists of modifying structural and functional components in order to adapt the product to the new requirements. Reconfiguration can be a way to create new product variants. We consider that "the development of families with different variants of the same product and the efficient use of resources have an important place in the current circular economy model" [2].

The perspective presented by Kuhl and Krause [4] shows the three possible strategies for product individualization:

- The manufacturer adapts the product to a specific customer;
- The products are tailored by the customer or self-individualization;
- Individualization without adapting individual products or services.

The role of the customer in the product individualization increases exponentially since he is actively involved in the design. Hu [5] show how the co-design of the product is possible between the client and the producer:

- Open architecture product, designed on the open platform that integrates standard, customized, and individualized modules;
- Personalized design, allowing the client to participate in different stages of the product development process. In this case, the process

flexibility must allow for collaboration between the designers with different expertise and experience;
- Manufacturing systems available on demand to quickly respond to CN (e.g., Additive Manufacturing);
- Participatory design with user-friendly interfaces for cyber-physical systems.

The products developed in recent years have become increasingly complex and, in most cases, they are no longer limited to a basic function. New products tend to meet several requirements and specifications for the user or the system in which they operate. Such products, with multiple functions capable of communicating and exchanging information in real time, are considered smart products. Intelligent products are integrated into the manufacturing process and actively participate in and control every step of the process. At the same time, intelligent products know their normal operating parameters and can provide information about the state in which they are throughout their life cycle [6].

The advanced technologies associated and integrated in the smart product development process, with communication and information collection functions, can redefine the new product design.

The literature review refers to research in the framework of the new product development, the smart product development, the open architecture product, in MI and MP. Finally, the future of production will be presented, consisting of modular and efficient manufacturing systems, enabling the purchase of individual products, preserving the economic conditions of MPr.

2. NEW PRODUCT DEVELOPMENT

In most cases, the development of new products in an industrial environment requires an updated version of the product design.

A new product version "involves novelty elements from a functional or design point of view, but at the same time, many of the specifications or technologies are taken from the previous product version, a process known as reconfiguration" [2], [7].

According to Tomiyama et al. [8], the phases of the product development process overlap. After defining the concept, the multidisciplinary design team work in parallel to complete the design.

Then the integration phase begins, and the software component develops. This activity requires a waiting time for the software team, which is subject to completion of the mechanical and electronic parts of the product. Also, this way of working means aligning some monodisciplinary teams, which until that time worked independently from each other at the end of each phase (Figure 1).

A traditional model for the product development process is the model V represented in Figure 2 [9]. On the left side of the model, the design of the system architecture is described, and on the right the integration, testing, and validation of modules and system takes place. It is worth noting that Model V should be regarded as a reference model and not as a descriptive model, as it does not fully reflect reality.

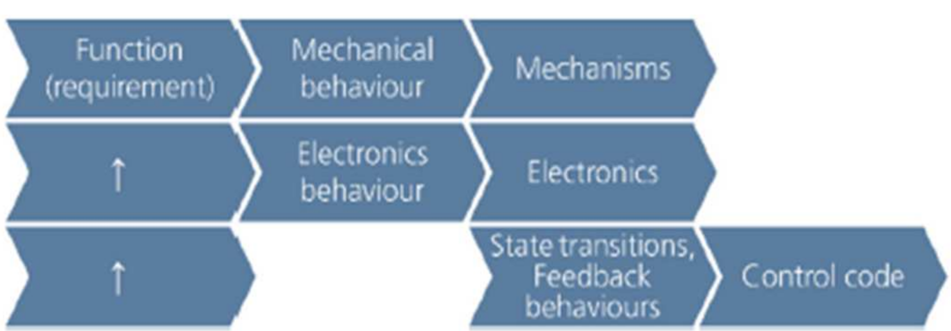


Fig. 1. Realistic representation of the development process [8].

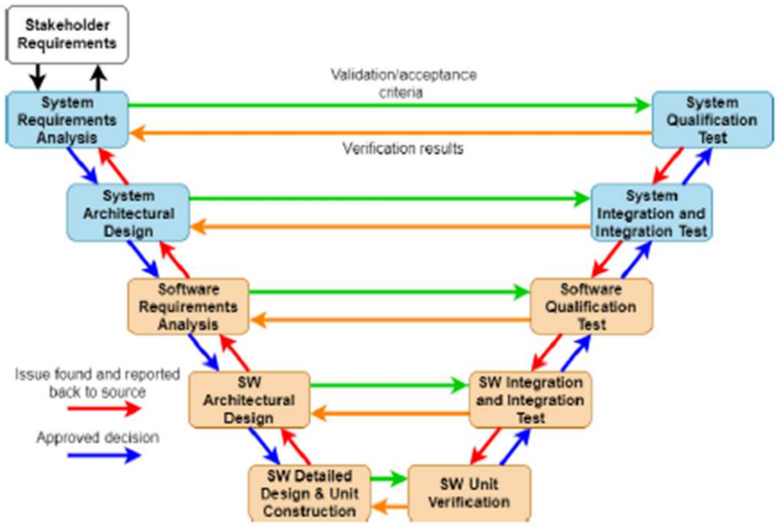


Fig. 2. Model V for the product development process [9].

3. SMART PRODUCT DEVELOPMENT

In the context of Industry 4.0, Smart Product Development (SPD) requires adapting the way of product design. Intelligent design, defined by speed, efficiency and reducing error, using databases, meets these criteria [3].

Databases store information on process steps, timelines, and execution methods. Reddy et al. [10] consider that "the main reason why databases should be integrated into the product development and design process is to reduce the resources involved in this process, up to 80 % of the time spent designing a product is consumed with routine tasks".

Repetitive tasks can be performed faster using Knowledge Based Engineering (KBE), and the time saved can be spent on creative activities. This increases the number of variants launched on the market in a shorter time and customized products can be manufactured (Figure 3) [2, 10].

Database systems simulate expert knowledge in a particular field. Sanya and Shehab [11] define an ontological approach using database systems as "a way to collect knowledge, find and record solutions or reuse knowledge later". The proposed approach consists of a qualitative research methodology that adopts best practices from previous ontology development methods, but focuses on encouraging modular architectural ontology design.

An Axiomatic Design (AD)-based approach to obtaining a smart product development process is presented in [12]. Based on these results, concepts and solutions of Industry 4.0 are derived.

AD is used to reduce the complexity of successfully applying methods from Lean Product Development (LPD) to Smart Product Development (SPD). The AD method starts with identifying CN and translating them into Functional Requirements (FR). Then, the search for Design Parameters (DP) corresponding to FR and decomposition of FR-DP pairs at different levels. The decomposition from top to bottom continues because DP represents more concrete solutions.

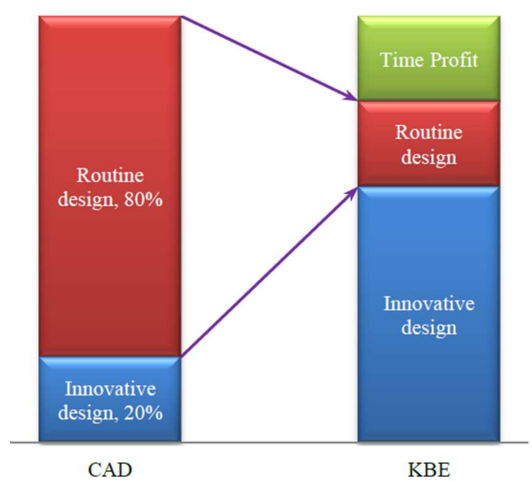


Fig. 3. Reduce the design routine using KBE [2, 10].

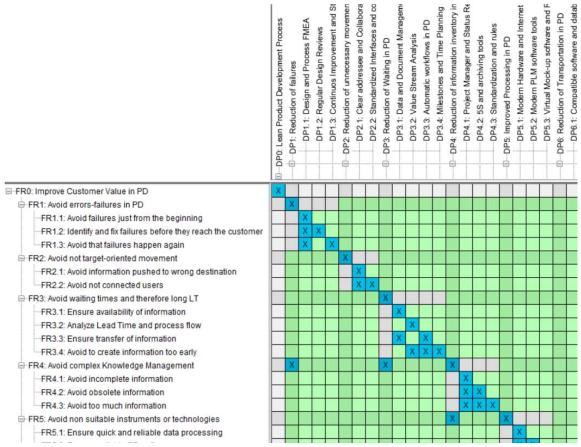


Fig. 4. Axiomatic design matrix [12].

Fig. 5. Methods to develop an OAP [13].

Figure 4 shows the design matrix at the second hierarchical level, obtained with the Acclaro DFSS software. The decomposition at the third level further allows for more and more concrete design parameters to be obtained into a highly structured and systematic top-down approach. By checking the independence and information axioms at each level, the complexity of design can be minimized.

4. OPEN ARCHITECTURE PRODUCT DEVELOPMENT

The methods to develop an Open Architecture Product (OAP) are proposed in Figure 5 [13]. The product structure is the interactive model of physical components to implement the product functions. Common product structures include integral and modular structures.

The integral structure is a product block for FR implementation. There is no clear limit to the functional components of the product.

Gogineni et al. [14] studied existing product development methods but concluded that they do not focus on personalized and individualized products. Figure 6 analyzes the product development methodologies against the criteria required for the development of personalized products.

Based on the obstacles encountered, the study presented in [14] identified the following criteria that underpin the process of developing personalized products:

- Engineering and Requirement Management;
- Focusing on the reliability of the product throughout its lifetime;
- Management of variants;
- The possibility of configuring via a configurator;
- Manufacturing or purchasing decisions;
- Simultaneous engineering;
- Use of information technology;
- IoT-oriented services.

Product methodolgies/ models	VDI 2221	VDI 2206	Engineering design by Pahl et al.	ISO 15288	Integrated product development	Autogenetic design therory	IPS2/ PSS development process model
Requirements engineering & management	◑	●	◑	●	◑	◑	●
Reliability and product lifetime consideration	◑	◑	◑	◑	○	○	○
Product configurator	○	○	○	◑	○	○	○
Variants management	○	○	◑	○	○	◑	◑
Make or buy decisions	◑	○	○	◑	◑	○	○
Simulatenous Engineering	◑	●	◑	●	◑	○	◑
Information technology - PLM	◑	◑	◑	●	◑	◑	◑
Service consideration for IoT (PSS)	○	○	◑	◑	◑	○	●

Legend
● Covered ◑ Partially covered ○ Not covered

Fig. 6. Methodologies for analyzing product development [14].

The same authors did an analysis of how current product development standards cover the criteria mentioned above. However, it is concluded that none of the methodologies analyzed fully covers the criteria set out. For example, although the product configurator plays a very important role in variant management, it is only mentioned in ISO 15288.

The involvement of the client in product design should not be analyzed in terms of cost minimization, but rather as a possibility to create a new value. In this sense, MPr, mass customization (MC), MP, and craft production (CP) are mainly based on the strategies: "Design of Customers", "Design with Customers", "Design by Customers" and "Design for Customers", as shown in Figure 7 [15]. While CP can allow customization up to the Market-of-One level, the cost of making the product is high.

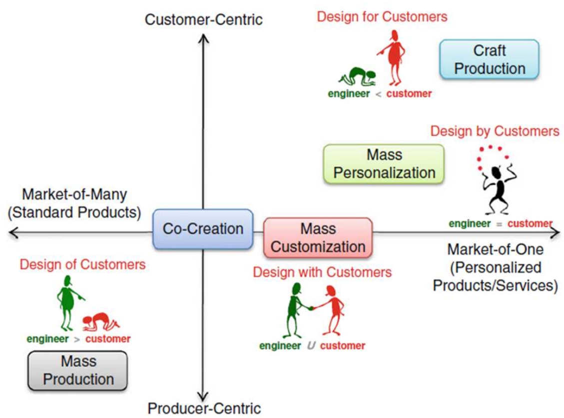


Fig. 7. Strategies to involve the client in product design [15].

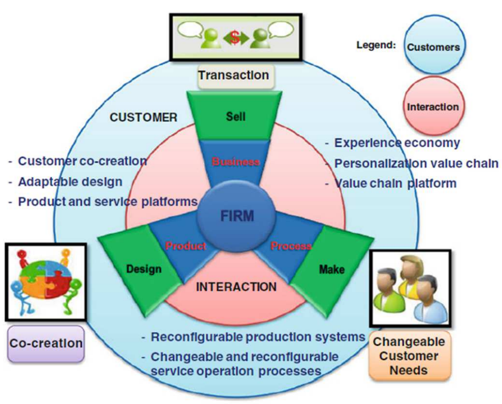


Fig. 8. Customer interactions with the business system [15].

In the MPr paradigm, the product is designed and standardized without the client's involvement. MC presents a process of passive choice from standard offer, in which the client is guided by designer and his participation is limited, i.e., configuration based on a product family that has been defined. MP assume more interactions with the client and their proactive integration. The vision of product design must change from the point of view of the physical product to a total approach to the product life cycle [15].

The process is geared towards a "customer-centric design" or a "customer-centered co-creation" strategy.

Zhou et al. [15] discuss an affective and cognitive design methodology for MP. The current practice of the concept of MC is manifested by a custom configuration paradigm, which means meeting the CN based on the legacy design. MP involves a strategy of producing goods and services to meet the latent needs of the individual customer, with values exceeding the costs for both customers and manufacturers. The affective and cognitive design for MP is supposed to address latent CN of the individual client based on the user experience. Affective and cognitive design decisions, which include the elicitation of "affective and cognitive needs, affective and cognitive analysis, and affective and cognitive fulfillment, are reviewed with a wide range of interests, including engineering design, human factors and ergonomics, engineering psychology, marketing, and human interaction with the computer" [15].

Figure 8 shows MP through client interactions with the enterprise system [15].

Customers can add custom functional modules to an original product to fulfill the requirements of the customized product using OAP [16]. Developing personalized products requires the participation of users to meet their needs effectively.

However, existing interactive Internet-based platforms and direct market user surveys cannot provide them with a complete experience of product characteristics.

To promote user participation in OAP development, Song et al. [16] suggest an interactive virtual reality system, consisting of an "interactive user interface, a product model processing module, a function execution module, and a data recording and analysis module" (Figure 9). To experience the product, users manipulate the product model in a virtual reality environment.

A key factor in custom MPr is the ability to adapt the product design to new requirements or circumstances. Adaptable design is a paradigm of product design that involves the ability to modify the design of a product or the product itself to meet new requirements or circumstances by adding or replacing modules using an adaptable interface [17].

Levandowski et al. [18] used the principles of adaptability to develop a product configuration platform. Other authors, such as Koren et al. [19], have also used the concept of adaptable design to create an open platform for the development of products.

Chen et al. [20] believe that "adaptable design has the potential to improve product competitiveness by meeting CN throughout the product life cycle". The adaptable design process with open and adaptable interfaces as well as a standard has been proposed for the design of OAP. For the optimal configurations of OAP, a mathematical model of adaptable design has been developed.

Because the consumer is directly involved in the product creation in the case of mass individualization, the chances that the finished product will meet its needs are very high. Companies offer co-design equipment to customers, such as product configurators [18], which allow customers to select from a list of available features, resulting in a product that meets their needs [2, 21].

Peng et al. [13] describe a web application that when the customer enters his requirements, looks for the right platform from an open-architecture product database. If more results are generated because of the search, the customer can provide more details to arrive at a single proposed solution. The structure of such an application is described in Figure 10.

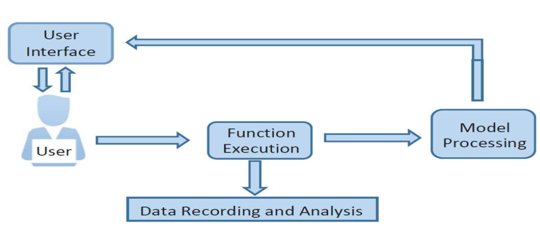


Fig. 9. Interactive VR-based system [16].

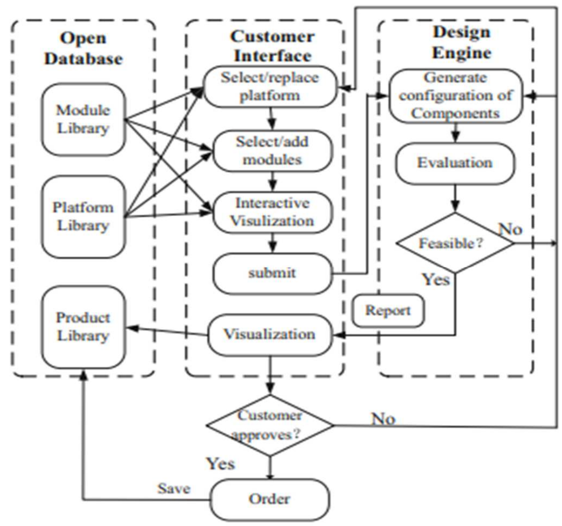


Fig. 10. The web application framework that allows the client to participate in the open architecture product design process [13].

Zheng et al. [21] delineates two stages of the development of an open architecture product configurator, namely (Fig. 11): the modular design stage, with macrolevel impact on the performance of a product family and the scalable design stage focused on the optimization of microlevel design specification.

5. THE FUTURE OF MASS PERSONALIZATION AND INDIVIDUALIZATION

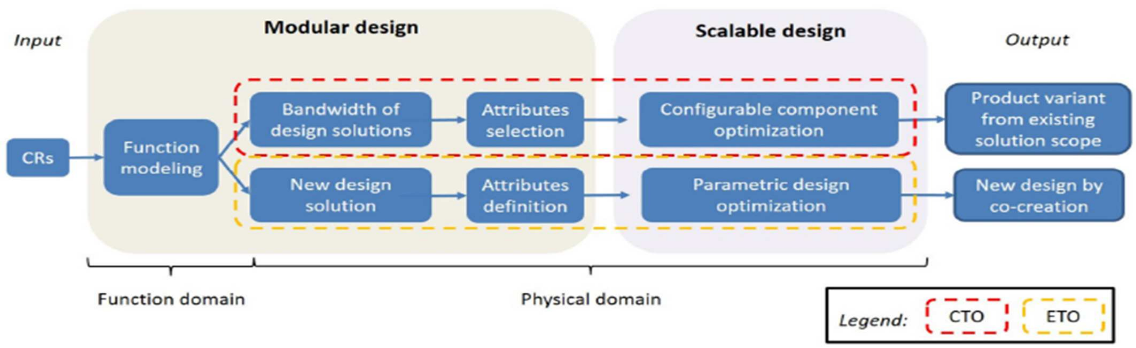
The future of production, according to Aheleroff et al. [22], consists of modular and efficient manufacturing systems that allow the development of individualized items while maintaining the economic conditions of MPr. These technologies can be seen in Figure 12.

Our opinion is that "the Digital Twin (DT), which can be a digital clone of a product, features, functionality, processes, or systems, is one of the technologies that lends itself to a high degree of product customization. Other Industry 4.0 technologies include the Internet of Things (IoT), Artificial Intelligence (AI), Autonomous Robots, Augmented Reality (AR), and Additive Manufacturing (AM)" [2].

The purpose of DT technology is to store the data collected by a smart product over its lifetime. If DT is integrated into Product Lifecycle Management (PLM) or Enterprise Resource Planning (ERP) platforms, it becomes relevant to the entire product lifecycle, not just the design or production phase. That is why DT is one of the technologies that underpin Digital Engineering. It is also the meeting point between the tools used in the development of smart products and the data collected during the product lifecycle. Given the context of Industry 4.0, the trend is to migrate to Digital Manufacturing. Thus, through innovation and high level of digitalization, companies will be able to define new business model and become more agile and competitive [23, 24].

7. CONCLUSION

The literature review of the new product development process, smart product development, open architecture products, in MP and MI showed the need to develop an OPA, modular and efficient manufacturing systems, which allow to obtain individualized products, in the economic conditions of MPr.



CTO=Configure to Order; ETO=Engineering to Order

Fig. 11. Proposed method for developing an open architecture product configurator [21].

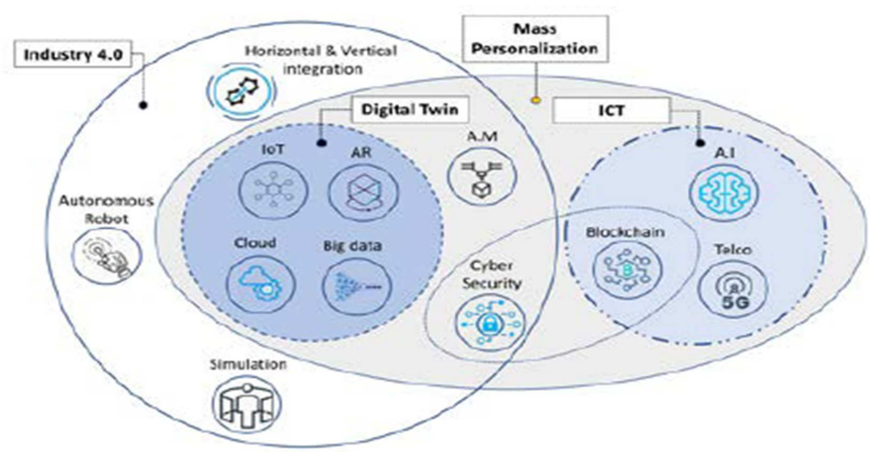


Fig. 12. Specific technologies for mass individualization [22].

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Sinteza cunoașterii privind dezvoltarea produselor în producția de masă personalizată și individualizată

Tranzițiile între cele trei paradigme ale producției evidențiază trecerea de la producția de masă la personalizarea și individualizarea în masă, urmare a cerinței de produse multiple, bazate pe module configurabile în diferite variante. Produsele au arhitectură deschisă sunt dezvoltate la cererea clientului și cu implicarea acestuia. Sinteza cunoașterii rezultată din cercetarea principalelor baze de date se referă la procesul de dezvoltare de noi produse, dezvoltarea inteligentă a produselor, a produselor cu arhitectură deschisă, în producția de masă individualizată și personalizată. Scopul cercetării îl constituie dezvoltarea unui configurator de produse cu arhitectură deschisă. În final se prezintă viitorul producției, constând în sisteme de fabricație modulare, eficiente, care să permită obținerea produselor individualizate, în condițiile economice ale producției de masă.

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