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An Overview of Product Design and Development Phases and Approaches

Yesufikad Fentie Takele[1]

[1]Ministry of Industry, Manufacturing Industry Development Institute, Addis Ababa, Ethiopia

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ABSTRACT

Recent trends in product design and development (PDD) emphasize innovative processes, stronger integration of customer input, and increasing levels of multidisciplinary collaboration in the development of new products. Product design should be strongly oriented toward meeting customer needs. Product development involves multiple phases and approaches, which can broadly be categorized into customer-focused and market-focused strategies. Successful and sustainable product development requires a structured progression through these phases. This review is based on recent research in product design and development, covering methods and techniques from idea generation through to the product launch stage. Overall, this paper explores the scope of product design and development (PDD) phases and approaches, while highlighting the role of technology in product design, particularly in reducing cost and time, improving production efficiency, and accelerating development speed.

1. Introduction

1. Introduction

The customer and market demand causes to the product to be produced. All end products pass through from the concept generation to finished product [1]. These processes are the design process and the product development process. Product design & development functions are very important areas in any production and, therefore, the interrelationship between them always principal importance [2]. Companies now a days are facing tremendous pressure to innovate and develop new products at an accelerated pace with declining price. In order to meet these business imperatives companies must take care of several key challenges to manage product conceptualization, design and development programs. New products or services, which are developed on a regular basis, are one of the main factors for sustainable success of companies. Product design and development together are essential to drive commercialization and growth in the manufacturing sector [3]. To capitalize on current and future market opportunities manufacturers should keep on focusing their product design and development strategies by evolving customers' requirements [4]. Different activities involved in the product development process are becoming extremely complex, as they require greater understanding and range of knowledge [5]. These activities must be formalized and structured in such a way that all the decisions should be made on proven knowledge and successful experiences [6].

1.1 Product design

Product design includes design related activities that occur during physical production. Product can be called as well designed only if it is well appropriate to its market. Basic elements of design are formulation of the design strategy, the design task, the way of designing, the use of an organization as well as the actual context and the designer's reaction upon it. In product design ideas and needs are given initially as solution concepts [7]. When a new product is to be formed several different solutions that can be embodied in concepts are often possible. Product design may involve adopting totally new products or may entail the refinement or upgrading of existing designs, to improve functionality, performance or appeal. Product design often correlates with the process of identifying a market opportunity and developing this opportunity into a proper feasible solution for real-world problems and users [8]. Product design is influenced by many factors, including aesthetics, functional requirements, and usage conditions.

1.2 Product Development

Product development is conceptualized as the set of activities needed for the conception and design to build the product, from the identification of a market opportunity to its delivery to the client [9]. In short product devElopment is transformation of a market opportunity and set of assumptions about product technology into a product available for sale [10]. Product development and product design can have separated in many aspects and integrated to give meaningfully product in manufacturing process. Loureiro et al. (2020) present several key distinctions between product development and product design, which are summarized in Table 1[11].

Table 1: The differences between product development and product design [11].

Feature	Product development	Product design
Scope	Involves activities from market research to the end of the product lifecycle	Involves details product design, verification and validation
Activities	Market analysis Product specification Sale Product design Manufacturing	Concept design Product architecture design Detail product design Prototyping and testing Verification and validation
Team	Sale Design Manufacturing Logistics	Design team Simulation team Verification and validation team

Figure 1: Product development activities.

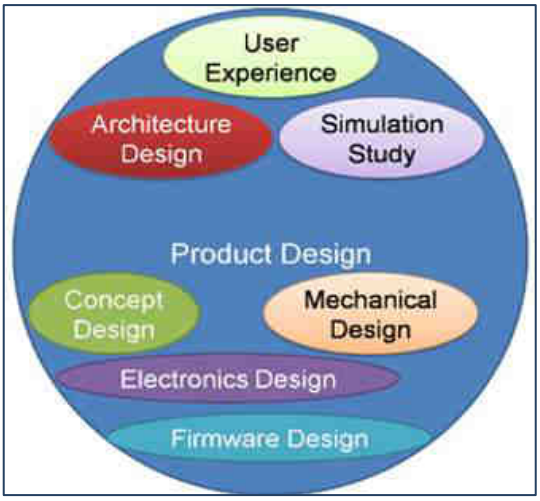

Figure 2: Product design activities.

2. Phases of product design and development

The product model is a simplified representation of the product. The product data model contains all data which describe the technical system and which are produced by using of process model. The process model is the central component of the product model [12]. All aspects of the life cycle need to be included in the development, by providing detailed knowledge collected from former projects, experiences, literature, and other internal and external sources [13]. Objective of earlier stages of product design and development is to make study of primary market, business and technical assessment. Objective of later stages is to actually design and develop the product. Many researchers have integrating the process of product design and development together, with different phases. Based on several recent literatures mainly focused on following basic phases.

2.1 Analyzing market and customers' needs

Customers' needs can be complex and multiple or sometimes very specific too. Normally customer's requirements are qualitative and tend to be imprecise and ambiguous due to their linguistic origins. In most cases, requirements are negotiable and may conflict with one another, and thus trade off become necessary. It is very important to be very clear about customers' needs and market trends [14].

2.2 Product concept generation

After defining the needs desired by the customers as well as the prospects of the existing market, then it can be defined the parameters of the product specifications to be designed [15]. A concept is an early representation of a product, incorporating only minimum details; just enough to show the main characteristics of the product. Concept describes and defines the principles and engineering features of a system or component which are feasible and which have potential to fulfill all essential design requirements. Concept development also involves the embodiment of various attributes into some kind of technological approach [16]. The selected innovative idea is transformed into concepts, where the marketer creates alternative product concepts from innovative ideas. Each organization will compare the alternatives that are feasible and will meet the customer needs [17].

2.3 Product design specifications

The product design specification is created during the planning phase or during the problem definition activity very early in the design process [18]. Much of the product design specification is driven by customer needs [19] . It is intended to show what the product should be and what it should do. It is necessary information in order to give the development team guidance on

development of the product to be developed. (Hemant and Saurabh 2017) are defines the marketing specification and technical parameters of the product [21]. Marketing parameters involve issues like- potential customer base, market constraints on product, expected product competition, target cost of the product, target production volume and market share, expected product distribution environment. Technical parameters involve issues like- expected product quality standards and requirements, product size and weight, product aesthetics and ergonomics requirements, product performance requirements (product life, service life, power requirements), material requirements, expected product reliability, product safety requirements, product service environment requirements, manufacturing process requirements and limitations , maintenance requirements, product recycling potential and expected disposal [22].

2.4 Design for manufacturing

Design for manufacturing involves the consideration of how parts and components will be produced and assembled. In plants where assembly is the main activity and there are many such facilities, design for manufacturing mostly makes considerations well beyond the ease with which components will fit to involve assembling processes and other downstream functions (Aston, 2017). The new techniques required the computer hardware and software such as SAP, CIM etc. As Meng, 2022 studied DFM is supported by computer-aided technology which integrates modern design methods, invention and creation methods, knowledge of various engineering disciplines, and computer software technology and integrates scientific knowledge of multiple fields. These became the modern trends and the most recent trends being combining the different techniques together to obtain a multipurpose tool that serves every possible purpose by leveraging the functionalities (e.g. SAP, PLM) the core business process will be integrated with Design and Development process. Designers should give closer attention to their ideas and drawings from the manufacturability, assemble point of view, redesign, re uses and etc. [23]. Design for Assembly (DfA) principles are widely used in product design, which has the benefits of simplification of product, reduction of manufacturing costs and overheads, improvement of product quality, and reduction of time to market [24]. The concept has been introduced since the early eighties, and many of the DfA methods provide design principles targeting general industry assembly processes. Min et al., 2021 stated that, the concept has been further developed and extended as Design for X (DfX) in industry, in which X may represent any feature, such as disassembly, cost , and sustainability [25].

2.5 Development of concepts and prototype

The prototype development stage of product design is when design concepts and solutions are developed through drawings and mock-ups or on Computer Aided Design tool. The solutions should meet the requirements of the product design specification. Elverum et al., 2016 explain the importance of prototyping in engineering design for a wide variety of purposes. The most common being to verify and validate assumptions, calculations and decisions during the development, as well as answering two fundamental questions: “Will it work?” and “How well does it meet the customer needs?”[10].

2.6 Detail design

This stage results in geometric models of assemblies and components, determination of precedence relations in the assembly, the detail design of the components including material and process selection, bill of materials, and control documentation for production. During the detail design stage, product development and design team strives to ensure that the physical manifestation of the design will meet the required design specifications. This reduces the number of physical prototypes required. In addition, it is possible to publish pre-release versions of future products. This allows stakeholders such as external customers, users or suppliers to participate in the product development process. They get an overview of the field of application and make necessary adjustments like ergonomic or aesthetic improvements. This increases customer satisfaction while reducing time and costs. In addition, the presentation of a future product in a realistic environment leads to a better understanding of functions and special features. It is possible to review “what if” cases and to improve decision making. Furthermore, future assembly and maintenance work can be simulated [22–25]. VR makes it possible to see a future product in a realistic environment before producing a physical part [26]. Computer-aided design (CAD) and computer-aided manufacturing (CAM) are closely connected technologies that play a vital role in linking initial product design to final manufacturing, significantly streamlining and improving the entire product development process [27]. Balzerkiewitz & Stechert,2020 studied the meaning of virtual reality (VR) in detail design for the purpose of PDD [29].

2.7 Design Evaluation

Design evaluation is a function which is carried out at various stages of the design process. Its purpose is to check that the design solution is in accordance with the original design objectives. Product evaluation begins at or before the start of product development with the formulation of customer acceptance criteria. Performance of product regards the information that determines the quality of the product being designed [14].

2.8 Product launch

For successfully launching and sustaining the product in the market, the voice of customer on their requirements must be responded. Strategic launch decisions govern what to launch, where to launch, when to launch, and why to launch. There is several factor that affects the product launch. Hemant and Saurabh 2017 identified some main factors of product launch,

seasonality, retailer's demand, sales force needs, market trends, innovation of new technology and government regulations can affect timing of product launch [30].

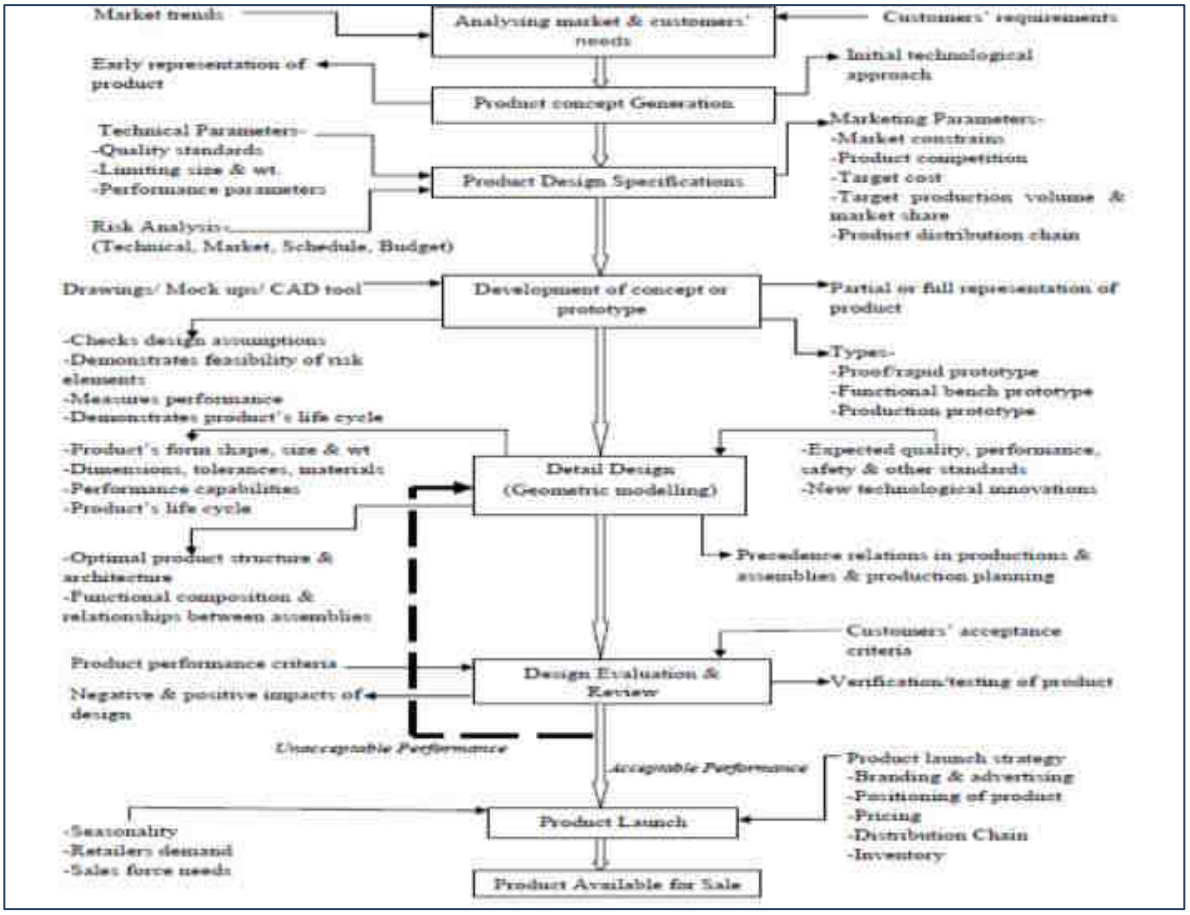

Figure 3: Product design & development process [15].

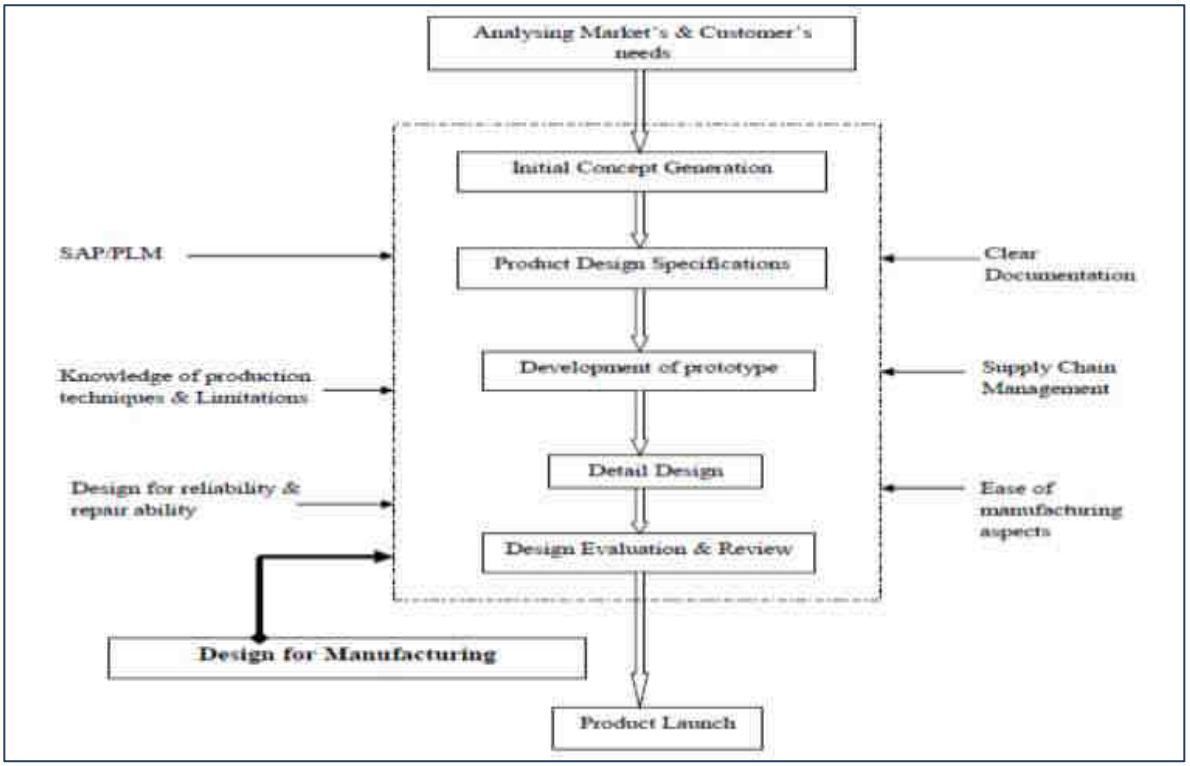

Figure 4: Design for manufacturing [6].

3. Different approaches of product design and development

The purpose of contemporary production technology is to ensure the correct operation of the first part in the shortest possible time and in the most cost-effective way. As the complexity of the product increases and the competitive life cycle of the product decreases, the implementation and testing of physical prototypes become the main bottlenecks for effective and successful production. In other hands Stief et al. 2020 indicate similarity index based approach product design improvement in the context of reconfigurable assembly processes, it will be integrated into the global approach. Integrating life cycle assessment, generative design approach which interrelated with artificial intelligence. Customer dominated Innovation process. Different literature shows several types of PDD approach Dalibor et al. 2019 stated model based systems engineering (MBSE) approach, sustainable product development and service (SPDS) approach [31].

3.1 Virtual reality PDD approach

Nowadays, there is no possibility to save costs and time for manufacturing and testing physical prototypes to detect blind sides and optimize design. Vice, "virtual prototyping" technology is used in design processes to shorten the costs and time of hard ware testing and iterative improvements to the physical prototype. A virtual prototype is a computer simulation model of a physical product that can be represented, analyzed and tested as a real machine [32]. As Ahmed et al., 2019; had mentioned the smart virtual product development system performs as a group of experts, which to captures, stores, maintains and reuses the experiential knowledge of all similar products. In addition, product design and development process improved by smart virtual product development approach in industry 4.0 [33]. Consequently, the virtual machine model in the design process and implementation of design changes until performance requirements are achieved will iteratively reduce development time and development costs [34].

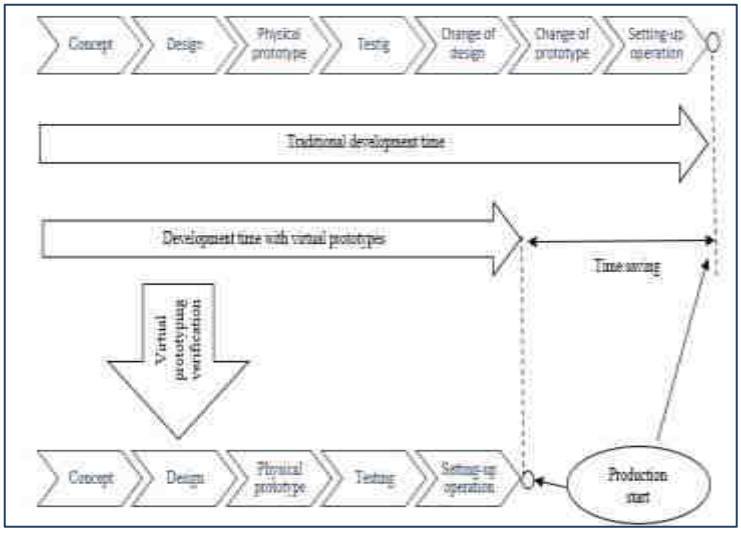

Figure 5: Comparison of the traditional design process and the design process with virtual prototypes, based on the Altintas et al. 2015 [35].

3.2 Innovative Approach

By correlated product component and functions, an innovative approach was utilized for the development of product designs to redesign, modifying parts and adding different component [36]. Chaochotechuang et al., 2015 based in its work area of Innovative approch, and stated for product development, process development, market development and organizational development. Additional product innovation can be from diffeent perspective like market perspective, technological perspective [37].

3.3 Adaption product development process approach

In other ways Almoslehy & Alkahtani, 2021 indicated that, adaption product development process approach which best approach to minimize the overall risk and thus to streamline the implementation of the proposed action plan and designed product specification. It shows to effectively manage risk in the product design process that hybridizes attributes of both the lean and agile design paradigms [38]. Further reduce time and costs, a product development process has been developed by adapted design approach for hybrid manufactured parts, like additive process to build a near net shape which will be machined to its final shape [39][40].

3.4 Total life cycle (TLC) approach

TLC for developing predictive design methodologies useful for modeling and optimizing the product performance and sustainability. The main purpose of integrating life cycle assessment (LCA) into the product development process (PDP) is to identify better options for the development of sustainable products. The information originated through LCA aligned throughout the PDP can be a key element to efficiently introduce an environmental sustainability perspective into product development, enabling the organization to achieve results for long-term competitiveness [41][40].

Figure 6: Total life cycle of products and the 6R concept [40].

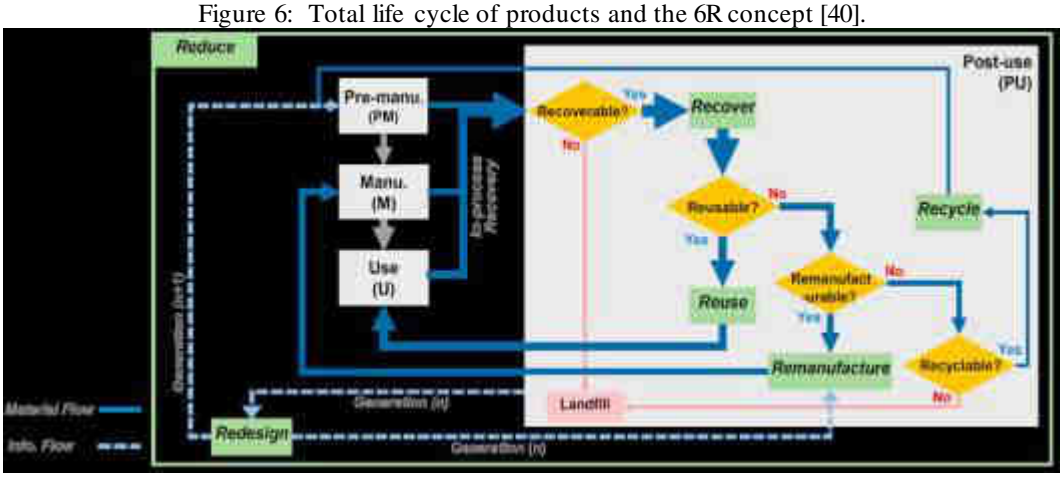

Figure 7: Total life cycle product design stages (adapted from) [40].

Table 2: Phase and approach of product design and development.

Product development design Approach	Manufacturing process	Reference
Innovative approach	The product components and corresponding functions that are generated by the patent analysis can be used to derive innovative products by approaches such as simplification or substitution.	[16][20][25]
Digital twins approach	Digital Twins is utilized as a tool to interpret customers' needs. The complete real-time simulation model can be seen as an interaction of several subsystems, such as environment, work process, mechanics, actuators, control system and user input	[39]
Artificial Intelligence Approach	It is likewise about contemplating studying how designers observe human intelligence to design, and with looking to make computer aids to design greater knowledgeable.	[45]
Model based approach	It's a systems engineering methodology that leverages modeling methods to support design, analysis, verification, and validation of systems.	[31]
Total life cycle approach	predictive capability is extremely useful for process planning, where careful planning and optimization of process condition	[43]
Adapted approach	Product development process enables the construction of parts optimized for the hybrid manufacturing and enables a rise in productivity by combining the advantages different process.	[40]
Similarity approach	Used guide the designer in the analysis of product similarity, the identification of product subassemblies to optimise and the choice of consistent assembly	[15][22][28]
Customer based approach	Customer Dominated production and design Process or customer acts as designer	[4]
Market based approach	New production can be developed depend on market feasibility	[2]

4. Role of Computer based technology in PDD

Smart CAD/CAM technologies for superior product modeling in the intelligence of designing complete product variants become more and more pertinent in future. Many design techniques to help interdisciplinary design actions in different engineering domains in addition to consequent processes have to be developed [47]. According to Pawan Sharma. 2014 manufacturing simulation uses a set of powerful CAD/CAM tools which seek to create virtual manufacturing environment. Many uncertainties which may result in time delay, rework or production of defective parts can be eliminated through simulation or manufacturing . It used to an integrated approach to carry out different activities in product development through seamless data transfer. CAD/CAM technologies help to simulate and the manufacturing like assemble analysis, better tool design and optimize manufacturing processes and agile manufacturing [48].

5. Role of Virtual Reality in Product developments

Smart Virtual Product Development (SVPD) system is a decision support tool to enhance the product development process for industrial manufactured products by using experiential knowledge. This experiential knowledge is stored, used, and shared in the form of set of experiences (SOE). The main components of SOE are variables, functions, constraints, and rules. Variables are the source of other SOE components and are the center root or the starting point of the structure. Functions create relationships between variables and are used to develop multi objective goals. Constraints are also functions and they are applied by SOE to get

feasible solutions and to control system's performance with respect to defined goals. smart virtual product (SVPD) system enhance the product manufacturing process [49].

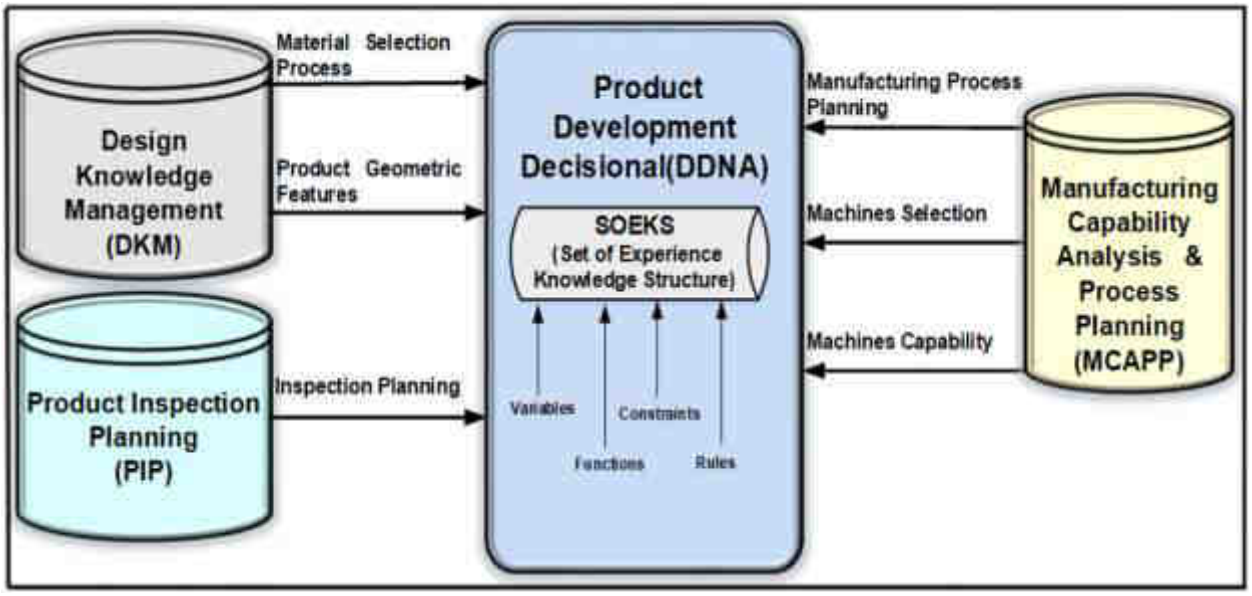

Figure 8: Architecture of smart virtual product development system [33].

Muhammad Bilal Ahmeda et.al proposed smart virtual product development (SVPD) system that consists of three main modules, i.e. design knowledge management (DKM), manufacturing capability analysis and process planning (MCAPP), and product inspection planning (PIP) [49]. It can be examining in the forms of SOE which showed in figure 8. In virtual reality the physical architecture is the core of the system design. It reflects the results of early design decisions. It is the basis for system optimization, system simulation, and subsequent detail design. The objective of physical architecture is to identify and rank all feasible physical architectures to assist designers in making decisions [45].

6. Role of Digital Twins in PDD

Digital twin increases the competence of manufacturing industries, enabling them to establish a systematic approach of adapting to fast changes. A wide diversity of tasks can be conducted through the simulation. Alaei et al., 2018 explained that, digital twin with the characteristics of ultra-high synchronization and reliability, convergence between physical and virtual product, etc., has high potential application in product design, product manufacturing, and product service [39].

7. Role of Artificial Intelligence in PDD

Artificial Intelligence can be used very effectively and efficiently for the design of the mechanical system, which reduces design time and cost to a very large extent. Hence, Artificial Intelligence will outcome in transfiguring and reforming industrialized surroundings at the traces of enterprise 4.0 or Internet of Things [45].

8. Conclusion

Generating new product ideas alone is not sufficient for successful product development; effective product design and development (PDD) strategies are also essential to translate these ideas into market-ready products. Successful PDD requires a systematic progression through multiple phases and approaches. This study identified key phases and development approaches that support competitive performance in global markets and promote sustainable product development systems. In particular, the stages from idea generation to product launch, along with fundamental approaches such as innovative, adaptive, and total life-cycle strategies, were discussed. In modern PDD, customers and market requirements are recognized as primary stakeholders, often taking precedence over designers and innovators. Furthermore, advanced technologies such as CAD/CAM, digital twins, artificial intelligence, and virtual reality are becoming central to customer-oriented product design and development strategies. These technologies enable customers to actively participate in the design process to better meet their needs. Although advanced digital tools and smart virtual technologies offer powerful capabilities for product design, simulation, and verification, their effective use requires skilled expertise in CAD/CAM systems and strong digital knowledge.

Conflict of interest

The authors declare no conflict of interest.

Ethical approval

This work does not require any ethical statement.

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