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# LITERATURE REVIEW ABOUT MANUFACTURING SYSTEMS FOR MASS CUSTOMIZATION AND INDIVIDUALIZATION

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***Abstract:*** *In the manufacturing industry, changes are fast and profound, in line with the new industrial paradigms. This article analyzes manufacturing systems in the context of individualized and customized mass production. The literature review was performed in the main databases using keywords: Smart Manufacturing, Smart Manufacturing Systems, and Reconfigurable Manufacturing Systems. The conclusion is that Industry 4.0 offers solutions for the development of smart manufacturing systems (SMS), and reconfigurable manufacturing systems (RMS) are well suited for mass individualization. The evolution of manufacturing systems and future trends are moving towards a new paradigm: adaptive cognitive manufacturing systems (ACMS). New research directions are needed to support this development.*
***Keywords:*** *Mass Customization, Mass Individualization, Industry 4.0, Smart Manufacturing, Smart Manufacturing Systems, Reconfigurable Manufacturing Systems, Adaptive Cognitive Manufacturing Systems.*

## 1. INTRODUCTION

In the manufacturing industry the changes are rapid and profound, in line with the new industrial paradigms, with the reduction of manufacturing series, *mass customization and mass individualization*.

*Industry 4.0* offers increased flexibility, mass customization and individualization, increased speed, improved quality, increased productivity, and allows companies to face different challenges, such as increasingly individualized products, shorter market time, and high product quality.

*Smart Manufacturing* (SM) uses the "newest technologies and advanced data analytics to facilitate the performance" and the ability to make decisions [1]. Due to the spread of sensors and IoT, there is a huge increase in manufacturing data, the volume of data, and the speed of data, and analysis helps to manage them through evaluation and processing.

Manufacturing systems have been adapted to the volume of production and the variety of products. Thus, if in mass production the manufacturing systems were dedicated and rigid with mobile assembly lines, the products have a unified structure, in custom production the products have a modular architecture, and the manufacturing systems are flexible. Currently, the trend is mass individualization of open architecture products, manufacturing systems are non-series or distributed, reconfigurable [2], [3].

In this paper an analysis of manufacturing systems is made in the context of customized and individualized mass production.

The literature review was conducted in the main databases (Google Scholar, Web of Science, Scopus, ScienceDirect, Elsevier, SpringerLink, IEEE) through the academic e-nformation platform, using keywords: *Smart Manufacturing, Smart Manufacturing Systems,* and *Reconfigurable Manufacturing Systems*. The most relevant information is provided below. Finally, the evolution and future of manufacturing systems will be presented.

## 2. SMART MANUFACTURING

### 2.1 Definitions and characteristics

*Smart Manufacturing* (SM), a concept launched in the US, "commonly referred to as Industry 4.0 in Europe, is the latest iteration of the industrial revolution" [4], [5], [6], [7], [8].

Kang et al. [6] argue that "SM, which is the fourth industrial revolution, is considered a new paradigm, a collection of state-of-the-art technologies, that supports efficient and accurate real-time engineering decisions by introducing various information and communication technologies (ICT) and converging with existing manufacturing technologies".

SM uses the latest technologies and advanced data analytics to facilitate system performance and decision-making ability. Wang et al. [9] "promulgate that due to the spread of sensors and IoT, a huge increase in manufacturing data, data volume, and data speed is felt, and data analysis helps to manage them through evaluation and processing".

In [10] a comparative analysis of two different terminology used for smart manufacturing is made: *Smart Manufacturing* (SM) and *Intelligent Manufacturing* (IM). SM and IM seem to be two parallel paradigms that have evolved independently. The literature studied reveals that SM appears more frequently with Industry 4.0 concepts.

Kusiak [7] defines SM as "an emerging form of production that integrates the production assets of today and tomorrow with sensors, computing platforms, communication technology, control, simulation, intensive data modeling, and predictive engineering".

Bi et al. [4] defines SM as "a type of production paradigm to improve system intelligence, where digital technologies are used to empower physical things in manufacturing products, to support data-based decision-making in any field and at any level of production operations and reconfigure systems to adapt to changes in customer needs".

In [11] SM is defined as a triumvirate made up of Data, Pattern and Knowledge (Fig. 1) and includes databases, features, support technologies, implementation pillars.

## 2.2 Generic model of SM

Modelling a system starts with the representation of the elements of the system. A smart manufacturing system is, in fact, a system of systems (SoS). SM is composed of a multitude of technologies and elements, such as [4]: *Internet of Things* (IoT), *Cyber Physical Systems* (CPS), *Big Data and Analytics* (BDA), *Cloud Computing* (CC), *Artificial Intelligence (AI)*, *Collaborative Robotics* (CR), *Machine Learning* (ML) etc.

"The newly developed concept, *Digital Triad* (DT-II), is used to represent an abstract system element of SM. DT-II is an extension of the concept of *Digital Twin* (DT-I), and DT-II includes activators to meet functional requirements" [4]. As shown in Figure 2, "a DT-II is a coalition of life models, digital models, and the corresponding physical models" [4].

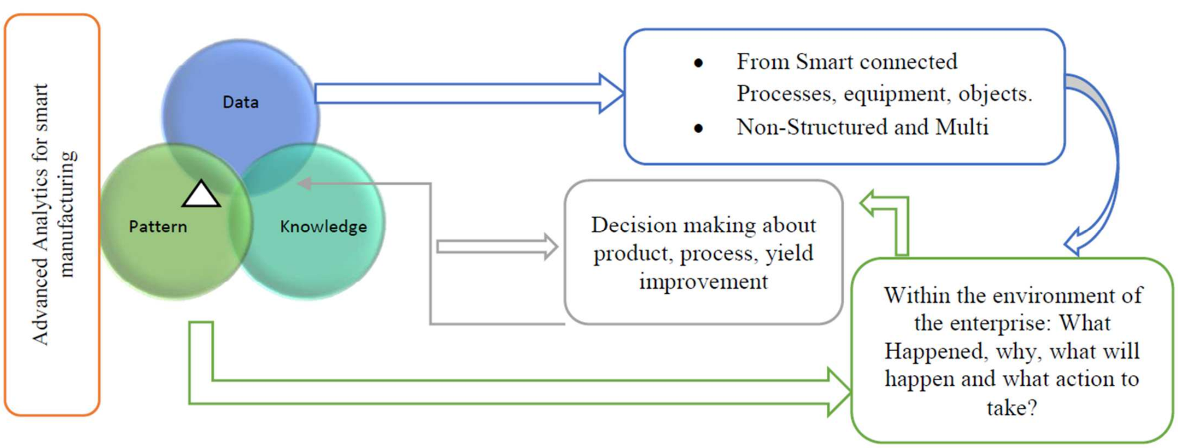


**Fig. 1.** Smart Manufacturing Triumvirate [11].

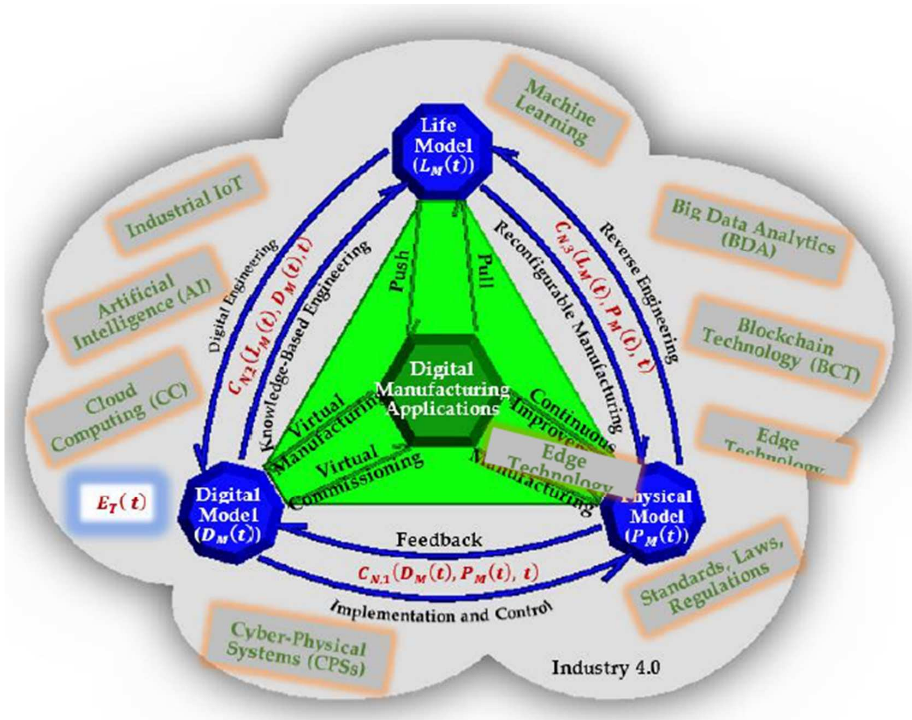


**Fig. 2.** The generic model of the digital triad DT-II(t) [4].

## 3. SMART MANUFACTURING SYSTEMS

### 3.1 Definitions and requirements

According to Romero et al. [12] "the intelligence of a manufacturing system includes the ability to communicate to exchange data and collect and report data on the status of production assets; built-in knowledge to represent human expertise and understand the elements of the system and the environment; learning capabilities by applying diversified algorithms, methods, and tools; judge mental capabilities for data-driven decision-making; the ability to feel, understand, and respond to environmental changes; control capabilities to ensure smooth manufacturing processes and to make and deliver products to end-users; self-organization to reconfigure systems to adapt to changes and uncertainties".

According to [4] "the intelligence of a production system refers to its ability to provide better manufacturing processes or to support better decision making in other production operations. Intelligence can be measured by a single system performance indicator or a combination there of, such as: degree of automation, cost-effectiveness, flexibility, robustness, flexibility, adaptability, sustainability, and resilience".

In [13] *Smart Manufacturing Systems* (SMS) are defined as "fully integrated collaborative systems that respond in real time to the changing requirements and conditions of the factory, the supply network and the needs of the customers by digitizing the production system".

Qu et al. [14] to make an analysis of the fundamental definitions of SMS.

From an engineering point of view, SMS is "an intensified application of advanced intelligence systems that enable rapid manufacturing of new products, dynamic response to product demand, and real-time optimization of production and supply chain networks".

From the interconnection and communication perspective, "the smart manufacturing system for Industry 4.0 uses sensors and data capture technologies at all stages of production. SMS becomes smart by the fact that the production rate increases, while errors and production waste decrease".

From the point of view of predictive analysis and decision making, "Big Data optimizes the planning and control of production operations, including predictive provision, predictive production, fault diagnosis, asset use and risk assessment etc.”.

SMS requirements are inspired by the Reference Architecture Model for Industry 4.0 (RAMI 4.0) and the Cyber Physical Systems (CPS) framework. The SMS functional model identifies the requirements of the activities and makes those activities efficient and based on the available software systems.

Based on the functional and technological requirements of SMS, the business requirements of SMS are proposed.

### 3.2 Conceptual framework of SMS

Achieving SMS capabilities requires replacing the classical architectural paradigm of the production system, based on a hierarchical control model, with a new paradigm based on distributed production services.

Figure 3 shows the conceptual framework of SMS in Industry 4.0 [15].

The horizontal axis presents aspects of Industry 4.0: smart design, smart monitoring, smart processing, smart control, and smart programming. The vertical axis presents other aspects of Industry 4.0: implementation of sensors and actuators data collection, data analytics, and decision making. Data collection and analysis are the main sources of smart work presented on the horizontal axis.

## 4. RECONFIGURABLE MANUFACTURING SYSTEMS

### 4.1 Definitions and characteristics

*Reconfigurable Manufacturing Systems* (RMS) were introduced into the circuit of theoretical and scientific research for the first time by the Center for Research in Engineering of the University of Michigan in 1999 [16].

“Under the paradigm of mass customization or mass individualization, manufacturing systems are often reconfigured in the production process” [17]. In the context of Industry 4.0, RMS are best adapted to mass individualization [2].

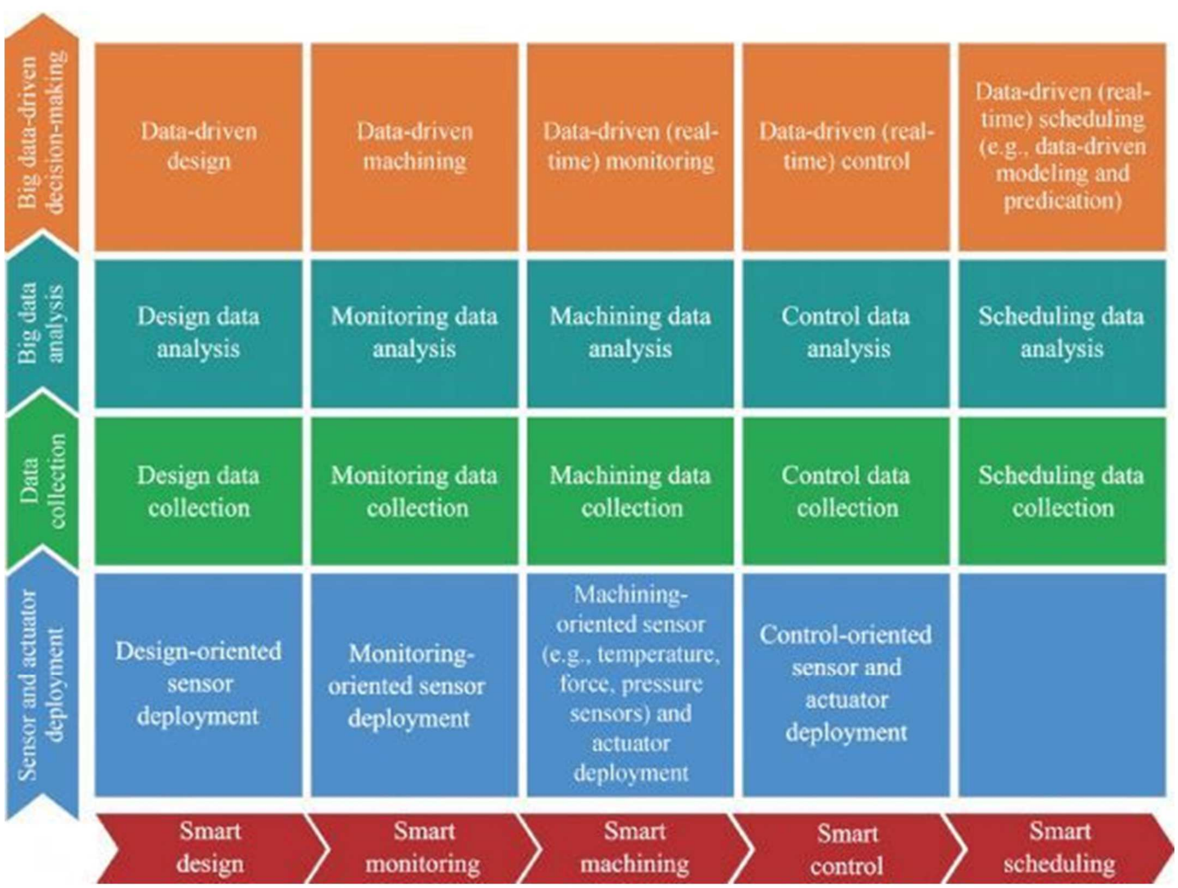


**Fig. 3.** Conceptual framework of SMS [15].

"A reconfigurable manufacturing system is a system designed to allow rapid structural changes, both hardware and software, to quickly adjust the production capacity and functionality of a family of parts in response to sudden changes in the market or regulatory requirements" [18].

Other similar definitions of RMS are summarized in [19]:

- RMS "is a manufacturing system that can be created by incorporating hardware and software core process modules, which can be quickly rearranged or replaced" [19], [20];
- RMS "is a modular architecture-based manufacturing system that selects two basic process modules, hardware and software, for fast, economical, and reliable reconfiguration or replacement" [21].

Therefore, the RMS has an "adjustable structure, both in the hardware architecture and in the software architecture and has six basic features" described in [19], [21], [22], [23] and presented in Figure 4.

*Convertibility* consists of the "ability to easily change the functionality of the existing system and machines to meet new production and market requirements" [19], [24].

*Diagnosability* is defined by the "ability of the system to read its current state and to detect and diagnose the causes of defects in the products to quickly correct them" [19], [25].

*Customization* is defined by the "system's ability to produce, within a product family, a product with specific customer characteristics" [25].

*Scalability* can be defined by the "ability to easily modify production capacity by adding or removing production resources and changing system components in response to changing demand" [19], [22].

*Modularity* is defined as a "division of operational functions into units that can be manipulated between alternative production schemes for optimal arrangements" [22], [23].

*Integrability* counts in the "ability to connect modules quickly and accurately through a set of mechanical, informative, and control interfaces that facilitate integration and communication" [22],[26].

### 4.2 Reconfiguration of the manufacturing system

As far as reconfiguration methods are concerned, they "could be classified into two categories, namely knowledge-based reasoning methods and artificial intelligence-based optimization methods" [17].

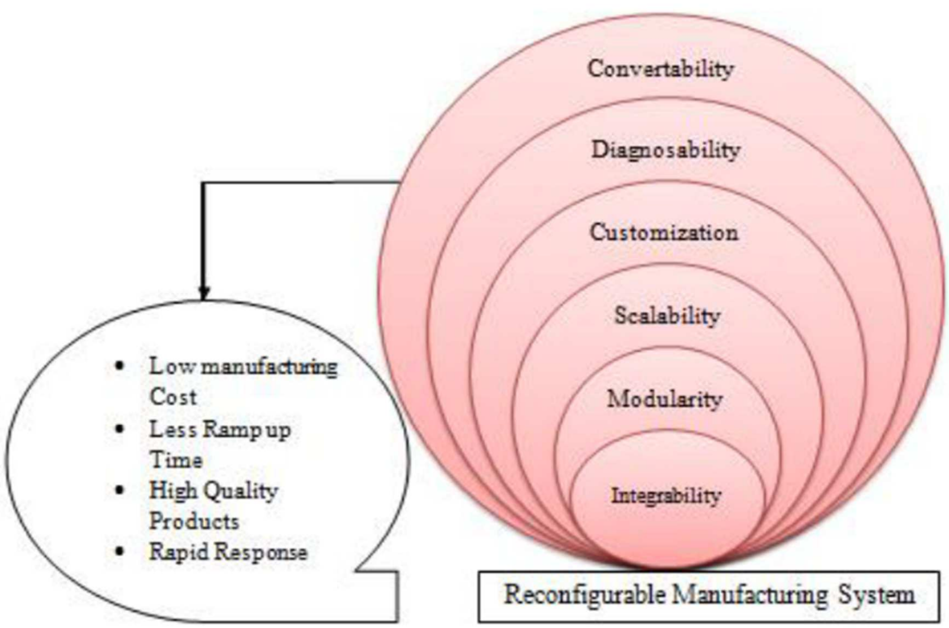


**Fig. 4.** Basic features of RMS [21].

"For the first type, the RMS knowledge automation technologies are distinguished as follows" [17]:

- the "ontology-based agent approach to achieve rapid reconfiguration" [17];
- the use of an optional measurement index to reconfigure the "usage rate and reconfiguration time based on axiomatic design" [17];
- reconfiguration "based on the Gale-Shapley game model" [17];
- automatic reconfiguration of Petri network controllers for RMS with an improved network rewrite system approach.

Second-type optimization methods are based "on the use of advanced artificial intelligence techniques such as Deep Learning and Big Data Analytics" [17] for:

- integrated optimization of the planning process;
- integration of system reconfiguration with production planning and product design.

Leng et al. consider [17] "a powerful online simulation tool to support the reconfiguration of the manufacturing system is twin digital technologies. Through a digital fast reconfiguration platform, the method forms a new reconfiguration after analyzing the difference between two products and deduces whether the current system can produce the given products".

As shown in Figure 5, "an RMS can be easily reconfigured at the system level (e.g., change of layout configuration), the machine level (e.g., addition of a new device) and the control level (e.g., integration of a new programming module)" [17].

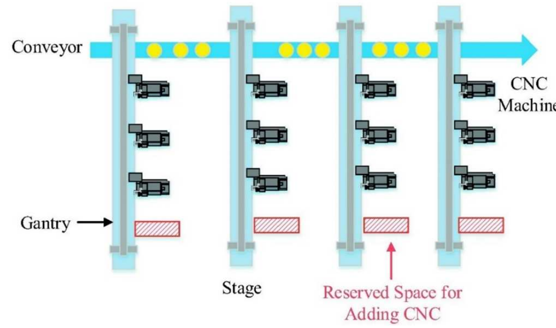


**Fig. 6.** RMS architecture for high volume production [23].

As shown in Figure 6, "a traditional RMS architecture for high-volume production consists of several stages connected in series, in which each stage is composed of identical parallel machines performing identical operations. These machines can be CNC machines, reconfigurable machines, or inspection machines. The machines are integrated by means of portals (one on the step) and a forward conveyor (or portal) that moves the parts through the system. Tampons are built between stages. This material handling system provides an RMS architecture with a high level of flexibility" [23].

"The main challenge in producing a variety of individualized products is that the variation in cycle time increases dramatically, which consequently decreases the efficiency of traditional RMS" [23].

To meet this challenge, Gu and Koren [3] "present a new system architecture that can meet the requirements of the mass individualization". This architecture "is modified based on traditional RMS, so it also possesses the six basic features of RMS" [23].

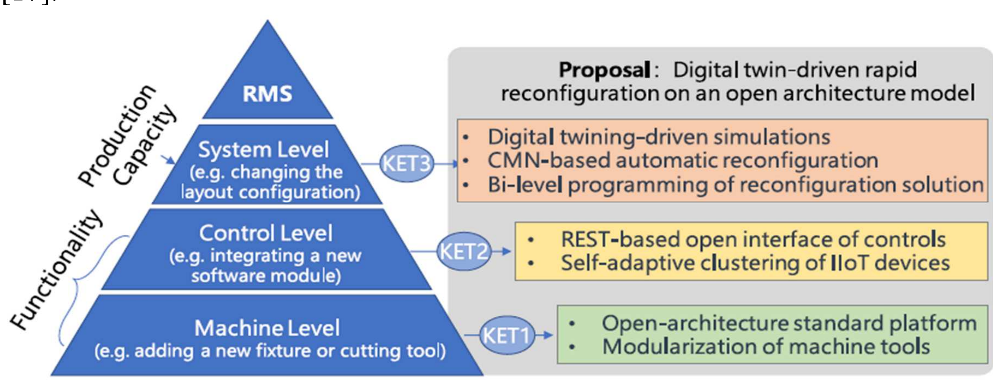


**Fig. 5.** Digital reconfiguration based on digital twin [17].

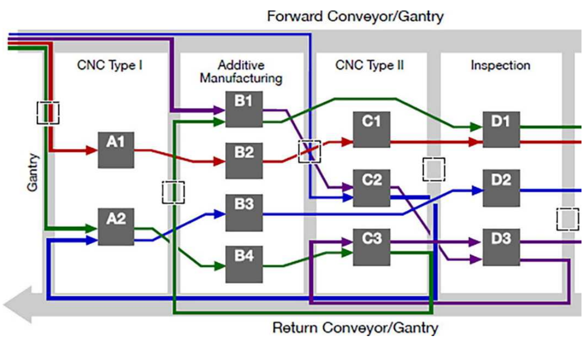


**Fig. 7.** RMS architecture for mass individualization [3].

An example of architecture proposed by Gu and Koren [3] is represented in Figure 7, "where stage A contains CNC milling machines, stage B additive manufacturing machines, stage C another type of CNC machine, stage D inspection machines, and assembly of different parts is performed in stage E either by humans or in human-robot collaboration. In this example, four different product variants are produced simultaneously. The main architectural difference between the traditional RMS and the proposed architecture for mass individualization is the addition of the return transporter (or return portal) that can transfer the pieces backward. By implementing both forward and return transporters, products can be processed into highly flexible routes, substantially improving system efficiency and resource use" [7].

## 5. TRENDS OF MANUFACTURING SYSTEMS

Manufacturing systems continue "to evolve in design, configuration, operation, and control, in an ecosystem characterized by more advanced factors and disruptive technologies and business models. Sociotechnical developments and business strategies will shape their future" [27].

The paradigm of manufacturing systems has evolved over time, influenced by changes in production, technology and production processes, production volume, and different degrees of automation, intelligence and adaptation" [27], as shown in Figure 8.

"The manufacturing industry continues to move towards general automation, while human-machine collaboration is advancing by

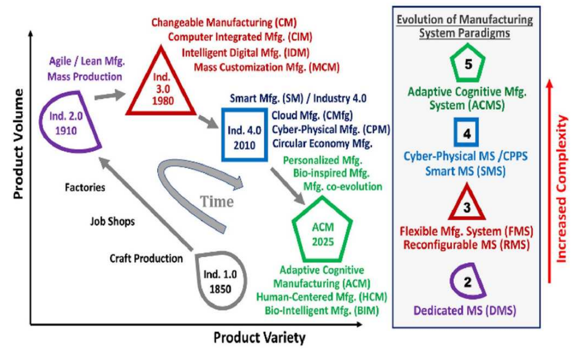


**Fig. 8.** Manufacturing paradigms and paradigms of manufacturing systems [27].

placing human operators in the spotlight. This sociotechnical approach to the evolution of the production system, in which automation is human-centric, cognitive, smart, and environmentally friendly, prompted an IEEE technical committee to call it 'bio-automation'. Others argued that these are features of the fifth industrial revolution (Industry 5.0). However, this terminology and associated implementations have not yet been widely adopted" [27].

*"Adaptive Cognitive Manufacturing* (ACM) uses Industry 4.0 technologies, including big data analytics and artificial intelligence, and generates useful information and interactions between humans and machines" [27]. All will be activated and supported by AI modules, smart sensors, extensive information and data analysis and actions and "methods of automated, cognitive and hybrid human-machine adaptation execution, as well as human experience and wisdom" [27].

"The evolution of production systems and future trends towards smart cognitive manufacturing are discussed in the context of the evolution of production along the industrial revolutions, from artisanal production to the current age of intelligent production and future bio-smart production" [27].

Such a new paradigm, *Adaptive Cognitive Manufacturing System* (ACMS), "will be enabled and made possible by predictive analysis, improved decision-making through artificial intelligence, and cognitive behavior, such as smart perception, planning, and action, as well as efficient connectivity and seamless integration" [27].

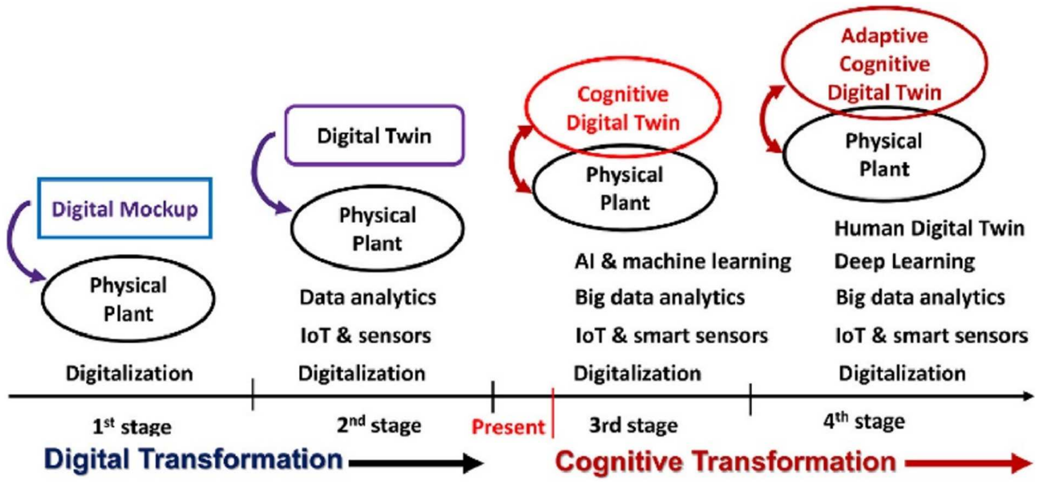


**Fig. 9.** Digital transformation towards adaptive cognitive digital twin [27].

The digital twin (DT) of manufacturing systems has evolved greatly since its appearance in 2002. Figure 9 shows the digital transformation towards the digital adaptive cognitive twin.

The expected manufacturing characteristics in the future, considering the four development axes, are:

*"Products* will be smarter, more complex, and environmentally friendly, have built-in systems and built-in intelligence, and use intelligent and self-healing biodegradable materials" [27].

*Technologies* will show "accelerated advances in computing, information technology, communications, artificial intelligence applications, machine learning and deep learning methodologies, the development of resilient machines, communicators, cognitive and more autonomous, and the deployment of biologically inspired technologies" [27].

*"Business models* will use digital business strategies and more diversity in operating models, new collaborative and partnership strategic networks will be used, and pay-per-use business models such as leasing and subscription will be implemented" [27].

*"Manufacturing systems will* have maximum flexibility, physical and logical scalability and agility, use more static, dynamic, and cognitive adaptation factors to improve productivity and highlight all three aspects of durability, enhance human-machine collaboration and shared decision-making, replace implicit interactions with explicit burden-sharing, and enjoy greater visibility throughout. Future manufacturing systems will use hybrid natural and artificial intelligence in the operation and control of systems. The use of autonomous machines, robots, production planning and control, improved diagnosis, predictive maintenance, and quality control will be extended" [27].

*"Digital and physical twins* will become inseparable for more efficient and optimal functioning, but people will continue to be an essential part of interactive decision-making at the operational, tactical, and strategic level" [27].

*"Humans* are the most adaptable and valuable assets in production systems. Integrating human experience and knowledge with the visibility of machine learning and cyber-physical digital and cognitive transformation requires new skills and improved multidisciplinary education" [27].

The paradigm of *"adaptive cognitive manufacturing systems* (ACMS) will become more predictive, adaptive, human-centric, and transparent, and will enjoy increased industrial acceptance" [27].

## 6. CONCLUSION

In the work an analysis of the manufacturing systems is performed in the context of custom and individualized mass production. Industry 4.0 offers solutions for the development of smart manufacturing systems (SMS), and reconfigurable manufacturing systems (RMS) are well adapted to mass individualization.

As manufacturing evolves to "the next stage, adaptive cognitive manufacturing systems (ACMS) systems, new research directions are needed to support the evolution of future production systems, with reference to: their digital and cognitive transformations; static, dynamic, cognitive and extreme adaptation methodologies; modularity, flexibility, reconfigurability, change, and response capacity; smarter, cognitive, knowledge-intensive, cyber-physical and biologically inspired manufacturing systems; autonomous systems better connected, integrated, and networked. Fully integrated and inherently smart systems, subsystems, and components will define the next generation of smart machines, systems, and businesses" [27].

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## Sinteza cunoașterii privind sistemele de fabricație pentru personalizarea și individualizarea în masă

În industria prelucrătoare schimbările sunt rapide și profunde, în conformitate cu noile paradigme industriale. În această lucrare se face o analiză a sistemelor de fabricație în contextul producției de masă personalizate și individualizate. Revizuirea literaturii de specialitate a fost efectuată în principalele baze de date folosind cuvinte cheie: Smart Manufacturing, Smart Manufacturing Systems și Reconfigurable Manufacturing Systems. Concluzia este că Industria 4.0 oferă soluții pentru dezvoltarea sistemelor inteligente de fabricație (SMS), iar sistemele de fabricație reconfigurabile (RMS) sunt bine adaptate individualizării în masă. Evoluția sistemelor de fabricație și tendințele viitoare se îndreaptă spre nouă paradigmă: sisteme de fabricație adaptive cognitive (ACMS). Pentru a sprijini această evoluție se impun noi direcții de cercetare.

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