11th International Conference on Through-life Engineering Services – TESConf2022
8-9 November 2022, Cranfield UK

# ICT infrastructure supporting seamless integration of certification procedures in microfactories

Pietro Perlo[a], Andre Rocha[b], Duarte Alemao[b], Nelson Freitas[b], Fabio Oliveira[b], Jose Barata[b], Panos Stavropoulos[c]*, Alexios Papacharalampopoulos[c], Nikolaos Tsoniotis[d], Charalampos Argyriou[d], Rayko Toshev[e], Tharanath Tharanath[e], Jani Sodergard[e], Saraev Alexandra[f] and Rafael Nunes[g]

[a]*I-FEVS, 10040 La Loggia, Torino, Italy*
[b]*UNINOVA-Centre of Technology and Systems (CTS), FCT Campus, Monte de Caparica, 2829-516 Caparica, Portugal*
[c]*Laboratory for Manufacturing System & Automation, MEAD, University of Patras, Patras 26504, Greece*
[d]*Ideas Forward, Thessaloniki 54655, Greece*
[e]*University of Vaasa, Yliopistonranta 10, 65200 Vaasa, Finland*
[f]*SPHERA, Leinefelden, Germany*
[g]*Belgian Welding Institute, 9052 Gent, Belgium*

* Corresponding author. Tel.: +30-2610-910-160 ; fax: +30-2610-99-73-14. *E-mail address:* pstavr@lms.mech.upatras.gr

**Abstract**

Digitalization can be considered as the main driving force towards achieving many different strategies, such as quality control and zero-defect manufacturing, green manufacturing and certified production. To this end, digital infrastructure in terms of Cyber-Physical Systems must be able to support various functionalities. The current work aims at supporting digitally potential micro-factories, in the sense that the minimum upfront investment is promoted. Also, herein, as a result of the EU H2020 project AVANGARD, where Cloud Manufacturing is tightly aligned with the concept of micro-factories and full production decentralization, the Blockchain architecture provides a secure interconnection layer, between all involved technology stacks, supporting in a modular fashion trust among disparate parties, traceability across organizational boundaries and a blueprint for seamless logging and auditing of activities by actors, software tools, IoT devices, and shopfloors, across supply chains. In addition, the concepts of end-to-end integration, MES & ERP involvement, link to the use phase (i.e. maintenance) towards through-life engineering services and finally procedures towards dynamic lifecycle assessment as well as a link to digital twins, are all discussed. The link to potential clients is also guaranteed. The case study of integrating Additive Manufacturing in such a production is used, indicating the added value of having interoperability as a criterion, even in the case where human-in-the-loop optimization of a factory is involved.

*Keywords:* microfactory; digitalization; ICT background; certification

## 1. Introduction

The manufacturing paradigm has been disrupted by globalization since nowadays producers and consumers can easily work together even when they are geographically apart. Furthermore, the demand for highly customized products, of high quality and low cost has increased, which has put the manufacturing industry to the test. In order to face this revolution, companies need to adopt new production paradigms and technologies, along with new business models. This implies, mainly, going from mass production to mass individualization, by leveraging production digitization, additive manufacturing, and increased exchange of data and knowledge [1]. Microfactories can be one solution but scaling the large automotive manufacturing factories down to small but flexible factories will be a challenge. Factory digitization relies on huge amount of collected data from the physical assets that are processed by data analytics tools, subsequently stored in cloud platforms. These interactions are facilitated by technologies such as Internet of Things (IoT), Cyber-Physical Production Systems (CPPS), machine-to-machine (M2M) communication protocols, and powerful data analytics algorithms [2]. Technologies such as Virtual Enterprise (VE), Virtual Manufacturing (VM) and Cloud Manufacturing (CM) which constitute the backbone of the microfactory concept have been explored and studied by different companies and researchers. A study by Helo et al [3], presents a methodological approach for VE and explains the corresponding interface of components such as visualization and configuration, message exchange, process designer, forecasting and simulation, optimization, cloud-based data storage, etc.

The wide adoption enterprise resource planning (ERP) systems has opened the possibility of managing industrial processes, business processes and other industrial subdomains like supply chains both within and beyond the scope of a company [4]. Whereas Manufacturing Execution Systems (MES) were developed to support planning and execution of operations closer to the machinery/production units. With the help of advancement in I4.0 technologies mundane industrial activities can finally be digitalized. For example, sensors and input panels can effortlessly connect and update the production information to the MES and ERP. Studies conducted by Mikko et al., [5], concluded that for distributed manufacturing, a new generation of internet-based, lightweight, easy-to-use-and-edit MES systems could provide the answer. In this project, a cloud-based middleware named "CloudAV" is developed, which acts as an intermediate system for the data exchange between ERP, MES and Blockchain "layers". The cloud hosted ERP system used is an open-source software known as Odoo. CloudAV demonstrates proof of concepts for different applications such as dynamic pricing, online pricing, vehicle configuration and pre-order auctioning, which requires real time data exchange between different services such as ERP, CRM and MES. Since the goal is to demonstrate the potential of the technology, pricing strategy or other optimal business operation strategies were secondary.

### *1.1. Data management & Certification*

The goal is to validate and build upon the premise of creating value via decentralization, potentially reducing shipping costs [6] and addressing the rise of mass customization in various sectors [7]. The road to achieving these efficiencies is being thoroughly studied under the term of Cloud manufacturing [8] and subsequent research works [9] aiming at putting forth a new paradigm where cloud computing, Internet of Things, and virtualization can transform traditional manufacturing into manufacturing as a service, where manufacturing resources can be openly shared under a secure and on-demand framework, addressing the complete product life cycle.

In the case of AVANGARD, where Cloud Manufacturing is tightly aligned with the concept of microfactories and full production decentralization [10], Blockchain technologies can provide a secure interconnection layer supporting logging and auditing, for all involved technology stacks, but also across organizational boundaries. This translates to a trustful environment supporting not only actor interactions, but further promoting autonomy of decision making at all levels, from facilitating supply chains and localized productions, to securing manufacturing shopfloors at the edge or the cyber-physical layer [11].

Life Cycle Assessment (LCA) is a methodology to assess the environmental impacts of products and services. It is noted that the methodology is described in the ISO norms 14040 [12] and 14044 [13].

As a microfactory allows for the production of products directly responding to customer needs and specifications, secure data traffic over the supply chain as well as inside the facilities and from the company to the customers is important. An optimized supply chain and manufacturing process requires continuous IT-based oversight which is linked to some environmental impacts to the use of computers, servers and network equipment. As an upside, tailor made manufacturing might lower the use of material and transport of finished products as a network of microfactories produces the specifically ordered bike or car in the region of the customer

Manufacturing Execution Systems (MES) were developed to help in production execution, by managing factories' activities. MES are able to monitor, control, and optimize the manufacturing processes within the factory. Decision-makers can use the provided information to take action and make decisions that provide process improvements. With new technologies emerging, MES allows the introduction and deployment of an Industrial Internet of Things (IIoT) environment, where all components may be connected and may interact, from the low level within the factory to the higher level of analytics tools [14]. It will build the bridge between the planning system (ERP, LCA, etc.) and the control system (PLC, SCADA, etc.), as shown in Fig. 1.

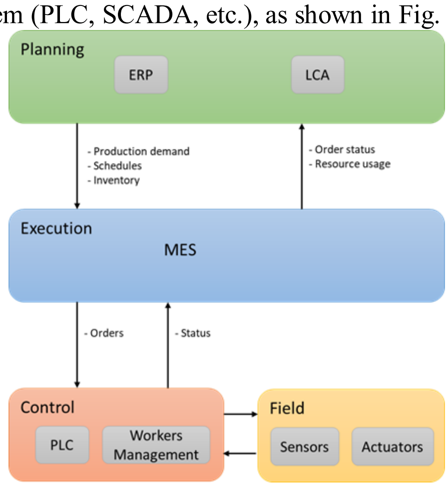


Fig. 1. Interaction between execution system and other systems.

The digitalization, and more particularly, the integration of digital twins, can even be considered as a special case of innovation absorption, leading to a specific set of induced costs and benefits (particularly in the case of a microfactory that deals with minimizing upfront investment [15]). It is not, in any case, straight-forward to address digital transformation within a company; there are various challenges in implementation [16]. There is, i.e. the training needed for the personnel to cope with the changes [17], the digital networking [18] and their interference [19]. As a matter of fact, to facilitate this procedure, JRC issued a questionnaire on the digital maturity of companies [20], as well as many other projects that takes into account the current maturity of SMEs; an example would be the connected factories project [21]. Circular economy can be also an extra paradigm where digitalization can play an important role.

In addition, manufacturing operations in general exchange sensitive data with a variety of actors Transactions between the aforementioned parties should be secure and unhackable by possible digital attackers [22]. With manufacturing becoming more and more decentralized, ERP/MES and other tools migrating to the cloud, and IIoT [23] becoming a reality, security as well as logging and auditing are becoming prominent concerns. That is why, according to Gartner, Blockchain technologies are one of the nine technological pillars in the context of Industry 4.0 expected to worth $176 billion by 2025 and $3.1 trillion by 2030 [24]. Technically, a plethora of benefits is provided through the use of Blockchain architecture on an industrial level [25-27], such as:

- Traceability of data
- Enhanced security through cryptography
- Transparency between the peers/nodes
- Accountability of supply chain partners, from raw material sourcing to distribution

### *1.2. Added Value & Applicability*

Summing up, the goal of the current work is to pave the way for a roadmap aiming at facilitating simultaneously green industry, innovation absorption, certification, as well as society-inclusion & profitability enhancing the competitiveness of the European manufacturing industry. The concept of the microfactory (minimizing the upfront investment) is crucial in this. In the current work, the microfactory is related to electric vehicles production.

## 2. Approach

The AVANGARD platform aims to deliver a fully interoperable and holistic platform capable of monitoring and optimizing the entire value chain, unifying the overall operations in a single customizable cloud-based platform, that can be leveraged in complex manufacturing environments and be instantiated across different cloud providers. The platform is divided into two big groups of functionalities, those running inside the factory and the ones running at the cloud layer (see Figure 2):

Factory level: Within the factory, an integration layer capable of connecting all the hardware will be deployed (Sensors, machines, stations, etc.) and existing software tools (MES, SCADA, etc.), with new tools capable of dealing with new functionalities and the integration with the cloud layer.

Cloud layer: The cloud layer of the AVANGARD platform is responsible to collect all the data from the different actors of the system (Factories, suppliers, transporters, customers, products, etc.) and allowing the integration of software tools enabling the macro level optimization, such as energy footprint of products, resource allocation, etc. The architecture relies on several entities. Those entities are connected to different interfaces responsible to connect the applications to the system. Among those entities are, for example, the Enterprise Resource Planning (ERP), the Manufacturing Execution System (MES), Blockchain or Lifecycle Assessment (LCA).

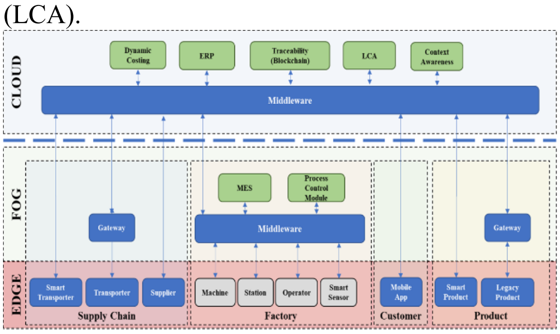


Fig. 2. The overall AVANGARD ICT architecture.

### *2.1. Data model & Blockchain architecture*

Since the AVANGARD architecture consists of five main elements that communicate between them, namely the cloud middleware, the supply chain, the smart factory, the customer, and the product, it is essential to support efficient and seamless communication.

The middleware hosted on the cloud will be the mutual point of interaction. Thus, all the other elements need to reach the cloud to share and exchange data, information, orders, and so on. In this way, each component will expose its functionalities to the others in order to be reachable, through a service-based approach, which means that all the components of the AVANGARD architecture will expose their functionalities as services, namely REST services. This way managed exposure and interactivity can be established. These services will be orchestrated by the integration layer and exposed through standard interfaces that are the point of interconnection between two systems or sub-systems. The communication in the cloud-based middleware was facilitated using JSON format as the data-interchangeable format for the multiple communications.

The new findings lead to an updated blockchain data model concept, which can support the generic architecture of the AVANGARD. To test the integration a new pilot was elaborated involving the following key components:

(1) ERP: The concept was that the ERP was to provide a customer interface, allowing a "customer" to place an order. This order was to be confirmed and subsequently forwarded accordingly to the MES component

(2) MES: The MES component was to provide manufacturing control and provide programmatic allocation to a 3D printer

(3) 3D Printer: The 3D printer was to execute a manufacturing command to print a customer defined component.

The systems and device communicated via a publish/subscribe approach as expected, with transactions being recorded directly to the blockchain component, providing the underlying layer for (a) logging transactional activities, including activity FlowIDs permeating from customer to printed material, and (b) proving the consent-based mechanism required for disparate entities (software providers, manufacturers etc.) to transact accordingly. Four nodes were implemented inclusive of the required services to support the AVANGARD architecture integration requirements, currently addressing the pilot and in place to support subsequent integrations, with real world manufacturing environments from other partners, with the help a modified Hyperledger Sawtooth implementation (Fig. 3).

A transaction family in Hyperledger Sawtooth consists of application-specific business logic that defines a set of operations and smart contracts. AVANGARD's transaction family smart contracts are responsible for altering the data stored in addresses under the AVANAGARD namespace. It is worth noting that the respective operations cover assets tracking in supply chain, as well as manufacturing operations documentation (i.e. welding quality monitoring and 3d printing execution support), whilst by exposing the Blockchain component as a REST based services layer the development restrictions in terms of end user internal programming capacities are lifted.

### *2.2. Connectivity to hardware & link to use phase*

An additional objective is to facilitate the trade and flow of information from one system to another system that benefits from the data. This process can be, for example, a machine sending its data to an optimization software that generates new knowledge and new inputs that then flow in the opposite direction to the machinery, optimizing the overall process. To control the flow of information of different machinery and software mentioned, a message broker approach was chosen, namely Apache Kafka, which uses a publish/subscribe model and allows to achieve high throughput rate, low latency, and scalability.

A holistic approach was implemented to test the integration from ERP to MES, before reaching the hardware (Fig. 4). The objective is to send an order to ERP that processes it and sends a production order to MES through Kafka. The MES will check if it can execute the order and if so, sends the order to a 3D printer that will start the printing process.

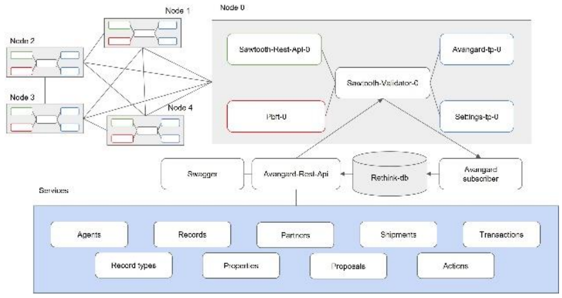


Fig. 3. Blockchain entities.

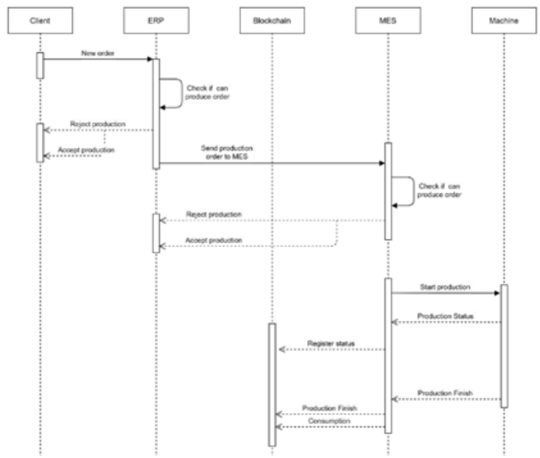


Fig. 4. Use case sequence diagram.

This type of connectivity also facilitates the link with the use phase of the vehicles, as per (i) the circular economy concept and (ii) giving feedback to design and manufacturing.

## 3. Results & Discussion

### *3.1. Visualization and auctioning*

The Covid 19 pandemic has reshaped consumer sales and marketing, with several studies indicating the increase in Digital sales [28-29] and thus increasing the necessity of Digital Retail System (DRS) in automobile industry more than ever. Recognizing this need, a proof-of-concept DRS system is developed and integrated to CloudAV.

The objective of this integration is to enhance consumer experience by allowing customers to select specific vehicle designs more effectively and by informing future product development about consumer preferences. In addition to this, a pre-order trading system is developed to allow users to trade their position in the waiting list for car delivery. Pre-orders and trading are logged to the Blockchain. Blockchain is used to log and thus track flow of actions longitudinally from the initial pre-order to the further steps. Blockchain provides transparency between customers and Digital Retail Systems about order processing and public trading between customers.

### *3.2. The paradigm of 3D Printing*

By extracting the energy consumption from the 3D printer, it is possible to analyze the consumption of each process and, consequently, the consumption of each product. This is possible to be done by sending data extracted from the 3D printer to a Kafka topic. These data are stored in a Postgres database and then, used by Grafana, an analytics and interactive web application connected to Postgres, allowing easy analysis of the database's content. Consequently, this will allow to analyze the data in real-time and take quick action to make improvements, or even to process the data with analytics tools that will try to optimize the energy consumption. Dynamic LCA is rapidly supported this way, through the various data aggregation.

### *3.3. Facilitation of Blockchain adoption*

Swagger based documentation was utilized to allow for ease of adoption by the involved partners. The documentation included permissioned access to all relevant textual references, along with code examples, to expedite partner onboarding as well as a source of reference (Fig. 5).

Supporting formal reporting [30] of manufacturing processes' KPIs in such a line is crucial, i.e. through a digital twin (DT). In addition, this can facilitate (i) real-time optimization with respect to quality and sustainability [31], (ii) reporting to any involved agent and (iii) DTs communicating with the Blockchain technology. The existence of experts, though, will probably be mandatory; they will just be network nodes considered in the case modelling, design and operation.

For all this to be able to work seamlessly and securely, the proper abstraction of information has to be taken into consideration. In Fig. 6, the non-encrypted records of the digital twin in the Blockchain are shown; within a predefined network of actors (suppliers, co-producers and clients), the acceleration of design for manufacturing is accelerated, achieving first time right. Also responding pragmatically to what-if scenarios is feasible, resulting in smooth processes operation. To this end, in any case, the extension of business contracts with the help of smart contracts is essential.

DTs are not alone in this, in any case, either due to technical inabilities, or due to human inclusion. Thus, in cases such as that of welding certification, manual data may be the case (Fig. 7).

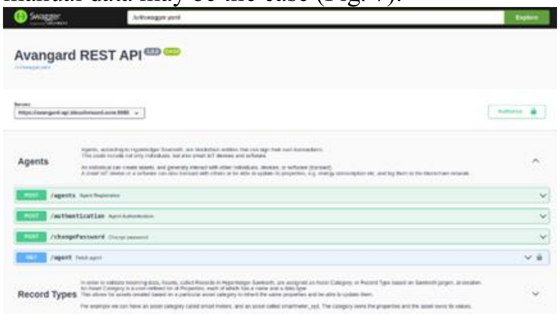


Fig. 5. AVANGARD REST API (Swagger online documentation).

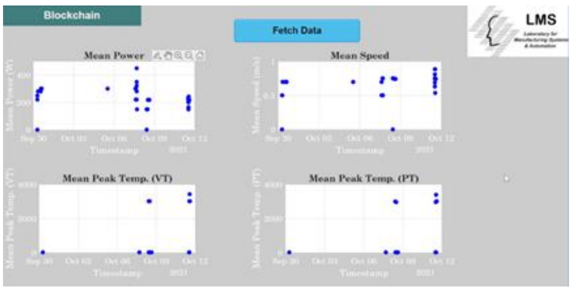


Fig. 6. Digital Twin sending data to Blockchain.

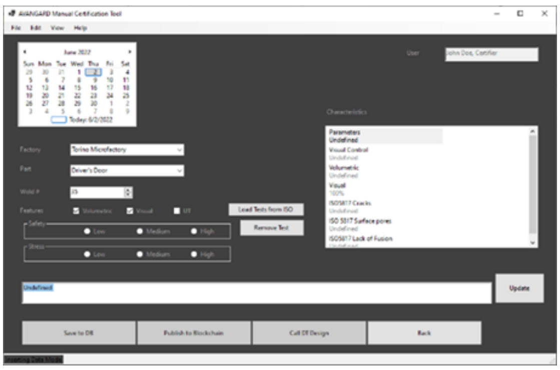

Fig. 7. Manual insertion of data to Blockchain.

## 4. Conclusions & Future Outlook

To sum up, based on the implementations of AVANGARD, it seems that the end-to-end integration followed by a carefully designed certification-support system, operating in a multi-level approach, is valuable for both Industry 4.0, through supporting digitalization and networking, as well as for Industry 5.0, backing up manufacturing and microfactories, in particular, towards human inclusion and resilience.

**Acknowledgements & Roles**

This work is under the framework of EU Project AVANGARD (European Union's Horizon 2020 R&I program, grant agreement No 869986). The dissemination of results herein reflects only the authors' view, and the Commission is not responsible for any use that may be made of the information it contains.

The roles are as per hereafter: IFEVS: documentation of microfactory, NOVA: ICT (Cloud architecture) & MES, LMS: digital twins & manual insertion of data, IDFC: Blockchain & Tracking, VAASA: machine to ERP integration & 3D Printing scenario, SPHERA: LCA aspects, BWI: certification procedure.

## References

[1] Gu X, Koren Y. Manufacturing system architecture for cost-effective mass-individualization, Manufacturing Letters 2018;16:44–48.

[2] Andronie M, Lăzăroiu H, Iatagan M, Hurloiu I, Dijmărescu I. Sustainable cyber-physical production systems in big data-driven smart urban economy: A systematic literature review. Sustainability (Switzerland) 2021;13(2):1–15.

[3] Shamsuzzoha AHM, Helo P. Virtual enterprise architectural framework: collaboration for small and medium enterprises. in International Manufacturing Science and Engineering Conference 2013; 55461:V002T04A004.

[4] Addo-Tenkorang R, Helo P. Enterprise resource planning (ERP): A review literature report. in Proc. of the World Congress on Eng. and Comp. Science 2011;2(5):19–21.

[5] Helo P, Suorsa P, Hao Y, Anussornnitisarn P, Toward a cloud-based manufacturing execution system for distributed manufacturing. Computers in Industry 2014;65(4):646–656.

[6] Durach CF, Kurpjuweit S, Wagner SM. The impact of additive manufacturing on supply chains. International Journal of Physical Distribution & Logistics Management 2017;47(10):954-971.

[7] Piller FT. Handbook of research in mass customization and personalization. World scientific 2010;1.

[8] Li BH, Zhang L, Wang SL, Tao F, Cao JW, et al. Cloud manufacturing: a new service-oriented networked manufacturing model. Computer integrated manufacturing systems 2010;16(1):1-7.

[9] Zhang L, Luo Y, Tao F, Li BH, Ren L, et al. Cloud manufacturing: a new manufacturing paradigm. Enterprise Information Systems 2014;8(2):167-187.

[10] Alptekin B, Tunaboylu B, Zaim S, Perlo P. Smart manufacturing of electric vehicles. In The International Symposium for Production Research. Springer, Cham 2020:767-773.

[11] Vatankhah Barenji A, Li Z, Wang WM, Huang GQ, Guerra-Zubiaga DA. Blockchain-based ubiquitous manufacturing: A secure and reliable cyber-physical system. International Journal of Production Research 2020;58(7):2200-2221.

[12] EN ISO 14044. Environmental management - Life cycle assessment - Require-ments and guidelines (ISO 14044:2006 + Amd 1:2017 + Amd 2:2020) 2020.

[13] Greenhouse Gas Protocol. Standards 2011.

[14] Stavropoulos P, Papacharalampopoulos A, et al A two-stage decision support system for manufacturing processes integration in microfactories for electric vehicles. Procedia Manufacturing 2021;54:106-111.

[15] Mantravadi S, Møller C. An Overview of Next-generation Manufacturing Execution Systems: How important is MES for Industry 4.0?. Procedia Manufacturing 2019;30:588–595.

[16] NIST blogs, 7 Manufacturing Digitization Challenges — and How to Overcome Them, accessed 29 June 2022, in https://www.nist.gov/blogs/manufacturing-innovation-blog/7-manufacturing-digitization-challenges-and-how-overcome-them

[17] Azarenko NY, Mikheenko OV, Chepikova EM, Kazakov OD. Formation of innovative mechanism of staff training in the conditions of digital transformation of economy. In IEEE International Conference IT&QM&IS 2018:764-768.

[18] Verhoef PC, Broekhuizen T, et al: Digital transformation: A multidisciplinary reflection and research agenda. Journal of Business Research 2021;122:889-901.

[19] Stavropoulos P, Papacharalampopoulos A, et al. Complementarity of European RIS Territories Towards Manufacturing Educational Products. In Working Conference on Virtual Enterprises. Springer, Cham 2021:738-745.

[20] Joint Research Centre of the European Commission, Digital Maturity Assessment for EDIH Customers, accessed in 19 May 2022, in https://digital-strategy.ec.europa.eu/en/activities/edihs

[21] Connected Factories project, , accessed in 19 May 2022, in https://www.connectedfactories.eu/autonomous-smart-factories-pathway

[22] Papacharalampopoulos Alexios et al. On the generation of validated manufacturing process optimization and control schemes. Procedia CIRP 2021;96:57-62.

[23] Hao Y, Helo P, Tsoniotis N, Toshev R. Blockchain-Based Supply Chain System in Automotive Industry for Small-and Medium-Sized Manufacturing. In: Bouras, A., Khalil, I., Aouni, B. (eds) Blockchain Driven Supply Chains and Enterprise Information Systems. Springer Cham 2023.

[24] Gartner. Gartner Predicts 90% of Current Enterprise Blockchain Platform Implementations Will Require Replacement by 2021, accessed 29 June 2022, in https://www.gartner.com/en/newsroom/press-releases/2019-07-03-gartner-predicts-90--of-current-enterprise-blockchain

[25] Fernandez-Carames, TM, Fraga-Lamas P. A review on the application of blockchain to the next generation of cybersecure industry 4.0 smart factories. Ieee Access 2019;7:45201-45218.

[26] Li Z, Wang WM, Liu G, Liu L, He J, Huang GQ. Toward open manufacturing: A cross-enterprises knowledge and services exchange framework based on blockchain and edge computing. Industr. Management & Data Systems 2018;118.

[27] Westerkamp M, Friedhelm V, Küpper A. Tracing manufacturing processes using blockchain-based token compositions. Digital Communications and Networks 2020;6(2):167-176.

[28] Soto-Acosta P. COVID-19 Pandemic: Shifting Digital Transformation to a High-Speed Gear. Information Systems Management, 2020;37(4):260–266.

[29] Kim RY, The Impact of COVID-19 on Consumers: Preparing for Digital Sales. IEEE Engineering Management Review, 2020;48(3):212–218.

[30] Turzo T, Marzi G, Favino C, Terzani S. Non-financial reporting research and practice: Lessons from the last decade. Journal of Cleaner Production, 2022:131154.

[31] Papacharalampopoulos A, Michail CK, Stavropoulos P. Manufacturing resilience and agility through processes digital twin: design and testing applied in the LPBF case. Procedia CIRP 2021;103:164-169