applied sciences

MDPI

Article

Challenges and Founding Pillars for a Manufacturing Platform to Support Value Networks Operating in a Circular Economy Framework

Paolo Pedrazzoli [1], Marzio Sorlini [1], Diego Rovere [1], Oscar Lazaro [2], Pedro Malò [3] and Michele Fiorello [1,*]

[1] SUPSI, Polo Universitario Lugano-Campus Est, CH-6962 Lugano, Switzerland; paolo.pedrazzoli@supsi.ch (P.P.); marzio.sorlini@supsi.ch (M.S.); diego.rovere@supsi.ch (D.R.)
[2] Innovalia Association, 48008 Bilbao, Spain; olazaro@innovalia.org
[3] Uninova, Universidade Nova de Lisboa, 1099-085 Lisbon, Portugal; pmm@uninova.pt
* Correspondence: michele.fiorello@supsi.ch

Abstract: Circularity is clearly a competitive advantage and a market opportunity for European industries. From this perspective, while digitalization is largely recognized as an accelerator and an enabler of Circular Economy, the fact that European industry is strong but fragmented (highly specialized medium- and small-sized companies have different needs and different tools) naturally results in the proliferation of commercial platforms for digitalized manufacturing. If such fragmentation is not properly addressed, it will eventually become a threat to European competitiveness. Despite some examples, value networks still do not operate in a seamless, transparent, and effective way. This paper addresses the challenges and the resulting technical funding pillars for an IDS (International Data Space) manufacturing platform meant to empower a fully digital circular thread of products and services.

Keywords: industrial cyber-physical systems (ICPSs); manufacturing platform; circular economy; data integration; data management; competitive digitization; sustainable circularity; International Data Space

check for updates

Citation: Pedrazzoli, P.; Sorlini, M.; Rovere, D.; Lazaro, O.; Malò, P.; Fiorello, M. Challenges and Founding Pillars for a Manufacturing Platform to Support Value Networks Operating in a Circular Economy Framework. *Appl. Sci.* **2022**, *12*, 2995. https://doi.org/10.3390/app12062995

Academic Editor: Dimitris Mourtzis

Received: 24 January 2022
Accepted: 14 March 2022
Published: 15 March 2022

1. Introduction

Businesses today typically use resources in a linear way. The externalities of the linear production model are threatening the economic and environmental sustainability of our planet, and the natural ecosystems thereon [1]. The World Economic Forum (WEF) Platform for Accelerating the Circular Economy (PACE) revealed that global resource use during the 20th century rose at about twice the rate of population growth. Furthermore, the comparison between economic growth and resource consumption in the past decade highlights that more resources are being consumed for every additional unit of GDP [2]. Circular Economy (CE) is a new paradigm that contributes to the positive reconciliation of all these elements [1]. Thus, CE is a bid to reduce the negative impact of organizations on their surrounding environment, while keeping businesses prosperous [3]. According to Accenture, the transition towards a circular economy (CE) is estimated to represent a $4.5 trillion global growth opportunity by 2030 [4]. Remanufacturing alone will, by 2030, attain an annual value between €70 bn and €100 bn, with the associated employment of 450,000 to almost 600,000 workers. According to the United Nations Environment Programme (UNEP) [5], Value-Retention Processes (VRPs, namely remanufacturing, comprehensive refurbishment, repair, and direct reuse) and recycling are complementary processes that, if pursued strategically, can contribute to GHG emissions reduction by between 79% and 99%. Similarly, the opportunity for material savings via VRPs is significant: compared to traditional Original Equipment Manufacturers new production, remanufacturing can reduce the new material requirement by between 80% and 98%; comprehensive refurbishing saves slightly more materials on average, between 82% and 99%. Repair saves an even higher share, between 94% and 99%; and arranging direct reuse largely does not require any inputs of new materials. Therefore, circularity is clearly a competitive advantage and market opportunity for European industries.

From this perspective, digitalization is largely recognized as an accelerator and an enabler of CE in business [6] and in production [7]. The fact that European industries are strong but fragmented (highly specialized medium- and small-sized companies with different needs) naturally results in the proliferation of commercial platforms for digitalized manufacturing, data handling, and management. If such fragmentation is not properly addressed, it will eventually become a threat to European competitiveness [8]. Within this framework, Circular Economy implementation is primarily a problem of information, where the digitalization of manufacturing business processes has been ongoing for decades, and stakeholders in value chains already have layered information systems. Despite some examples, the existence of those systems does not mean that value networks operate in seamless, transparent, sustainable, and effective ways [9].

This paper addresses the challenges and the resulting technical funding pillars for a manufacturing platform meant to empower a fully digital circular thread of products and services. Section 2 will provide a well-referenced framework of the current challenges still standing in the way of a fully digital value chain. Section 3 introduces the International Data Space (https://internationaldataspaces.org; accessed on 10 January 2022) policies as a founding concept for a common data space. Section 4 brings forward a framework for a technical solution that leverages IDS and the FIWARE open-source platform (https://www.fiware.org; accessed on 10 January 2022), while Section 5 discusses the results achieved.

2. Challenges

For European manufacturing to leverage competitive circular economy advantages, the industry at large must face the digital transformation process, addressing the digitalization of agile and sustainable value networks, towards a data-driven circular-economy-based production. However, several challenges are still standing for the next generation of a B2B platform for a fully digital industry and value chain, having a direct impact on the implementation of circular principles at the company and network levels [10]:

Challenge 1—The silo effect has not been actually relieved, and interfaces are only partially developed [11]. Information silos occur whenever a data system is incompatible or not integrated with other data systems (at the technical architecture level, at the application architecture level, or at the data architecture level). According to the London School of Economics, this is one of the greatest stumbling blocks that companies identify in their attempts at better utilizing data. The causes are numerous: inconsistency in the systems being used, different data formats, lack of a coordinated data strategy, lack of technology integration, and legacy technology barriers. The silo effect hampers data exchange between companies belonging to the same circular value network. This results in a twofold challenge to circular economy practices: on the one hand, the effective resource and service sharing required by industrial symbiosis is hindered by the corresponding lack of data sharing; on the other hand, the optimization of products' lifecycles and the generation of Product Service Systems (PSS) need data concerning different product lifecycle phases to seamlessly flow within a single organization and along the entire value network.

Challenge 2—Too many overlapping standards and vendor-specific platforms make interconnections laborious [12]. Standards are key enablers in manufacturing. Standards provide data definitions, detailed models of the information relationships, and interface protocols for the product and process lifecycles. They support product designs and management, production system design and operations, and integration into business value chains. These are the foundations on which information can flow throughout the levels of manufacturing control and between partners in a manufacturing enterprise, including the various software vendors and devices. Overlap between standards is caused both by the differences among regional, national, and international standards systems, and by the fact that standards in the same technical areas, but in different application sectors, are defined independently (e.g., material-testing methods defined for different industry sectors are often not consistent). CE approaches stimulate companies to break down barriers with suppliers and partners that, especially in this context, may belong to either geographically or sectorally remote industries. The players of the circular value chain may thus refer to different standards and data-management platforms, restricting the possibility to connect them and let them work on a shared value.

Challenge 3—Lack of secure exchange of data and clear data ownership [13]. Fundamental data security must deal with several challenges, such as data tampering, eavesdropping and data theft, falsifying user identities, password-related threats, unauthorized access, and lack of accountability. As far as ownership is concerned, existing liability laws are based on the concept of tangible products. Companies cannot be sure whether they can recourse to this legislation for data, so they prefer to fall back on contractual liability on a case–by–case basis, and not on the potential that new technologies offer. The implementation of CE practices, including the exchange of resources intra- and inter-companies, sharing of knowledge, energy demand, and response optimization, as well as of the assessment of companies' sustainability performances, requires sharing data and information that are often private and sensitive (i.e., primary and foreground inventory data). The proper management of data and decoupling of sensitive information would result in the elicitation of circular opportunities for companies and in the possibility to "externalize" the management of such data, enabling an effective decision-making process and assuring trust and rewarding circular behaviors.

Challenge 4—No effective and reliable LCA data sources [14]. The measurement of the sustainability performances of products and companies has been largely recognized as a pre-requisite for the actual translation of sustainability-driven strategies into operations, towards the implementation of the triple bottom line concept in everyday industrial practices. For these reasons, proper metrics must be adopted enabling the standardized calculation of appropriate indicators measuring the economic, environmental, and social performances at product and company levels. This notwithstanding, the application of LCA, LCC, and S-LCA meets several barriers for businesses due to their high degree of complexity and demand for high-quality and high-quantity data. Data gathering from the different entities along the supply chain is probably the most critical issue to be solved, also considering that the completeness and quality of data are fundamental for the reliability and repeatability of the calculated impacts. If the use of primary data enhances the quality of the results, since they address specific products flowing through the manufacturing network, the collection of this kind of data requires extraordinary effort, especially when real-time assessment or the traceability of a specific production lot is needed, or when the data in analysis have to be collected from suppliers and, especially, from (n-tier) suppliers of suppliers. Current LCA tools are not integrable with the already existing data management platforms and, in most cases, information is retrieved manually and then replicated in a different environment with the risk of decoupling the descriptors of a single item. In the CE context, two main aspects related to Life-Cycle Assessment methodologies have to be considered: LCA metrics for CE and a framework to support the implementation of CE based on LCA evaluations. The criteria for the evaluation of circular practices adoption by organizations are still linked to local initiatives, or are in their embryonic stage so they are not already acknowledged in the industrial and academic contexts. Advancements are also required to properly integrate LCA in CE practices, thus enabling company decision-making processes related to circularity to be structurally based on a standardized set of circular metrics.

Challenge 5—Poor use and exploitation of IoT-enabled data streams [15]. More and more companies are realizing that the large amounts of information that they accumulate can play a critical role in the decision-making and creation of new business. However, there are some challenges ahead, as almost any organization that wants to implement Big Data exploitation encounters technology gaps. Conventional approaches are not designed to extract the most out of the large volumes of information; thus, challenges include mass data storage, integration of multiple formats and multiple sources, and processing and obtaining results in real time. CE approaches ask to trace products along their whole lifecycle to (1) recover in the production phase valuable components and materials that, in a linear vision, were considered as scraps, (2) monitor during the use phase the optimal use of consumables and maintenance needs, and (3) map the product in its end-of-life in order to enable its possible reuse and/or recycling of components and materials. Traditionally, this information is available in the form of tacit knowledge, practical experience, customer feedback, paper manuals, software, hardware, pictures, and advanced specifications. Collecting and transferring information about environmental phenomena, physiological parameters, or user habits will give birth to a wide range of applications and customized services, irrespective of the application domain [16]. The new possibilities offered by IoT-enabled data streams, in data gathering from the different product lifecycle phases, from production to use and end-of-life, are still untapped, while they could make available the information needed to close the loops and improve material and energy efficiency.

Challenge 6—Industry needs good examples, which are not available. In a scenario where 85% of companies see "data" as the top investment area in the next 3 years [17], concrete industrial examples of the exploitation of those data to generate business value, in a circular economy value chain, are missing. Additionally, those examples, to be effective, need to clearly demonstrate the role and advantages of both large-scale companies and SMEs, as European competitiveness cannot afford a two-speed Industrial Data Platform market that leaves SMEs behind. As CE is not yet an established model for industry, the availability of success cases results in making CE attractive to companies selling them the experience and showing the value.

Those challenges depict a scenario (Figure 1) where diverse manufacturing platforms, implemented within different companies, suffer from several data-related gaps, hindering efficient circular flow implementation.

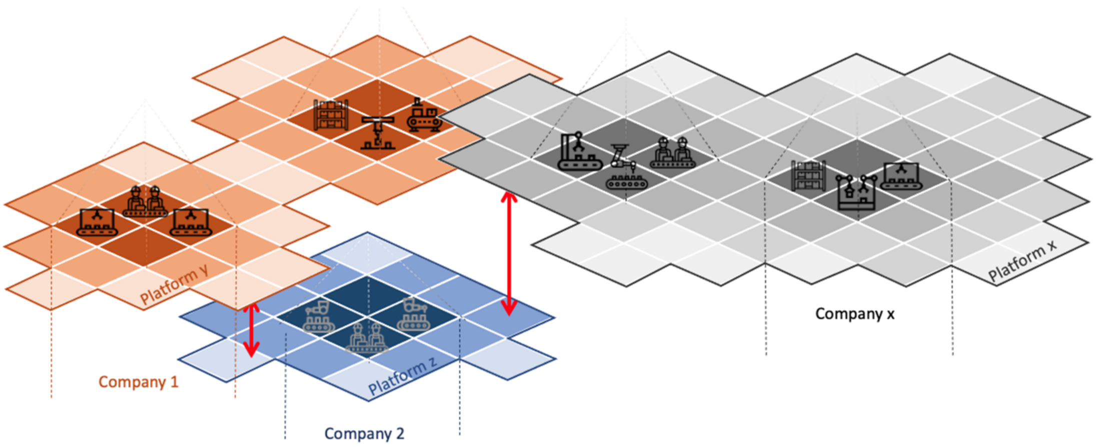

Figure 1. Gaps in the manufacturing networks.

3. Envisioned Future Scenario

This paper lays the basis for a new manufacturing platform that lives as an ecosystem of open platforms and commercial solutions meant to "level" the aforementioned gaps (Figure 2), providing a common data space to implement a platform of platforms, to promote and facilitate the secure and seamless exchange of manufacturing/product/business data within value-networks in a circular-economy-based ecosystem.

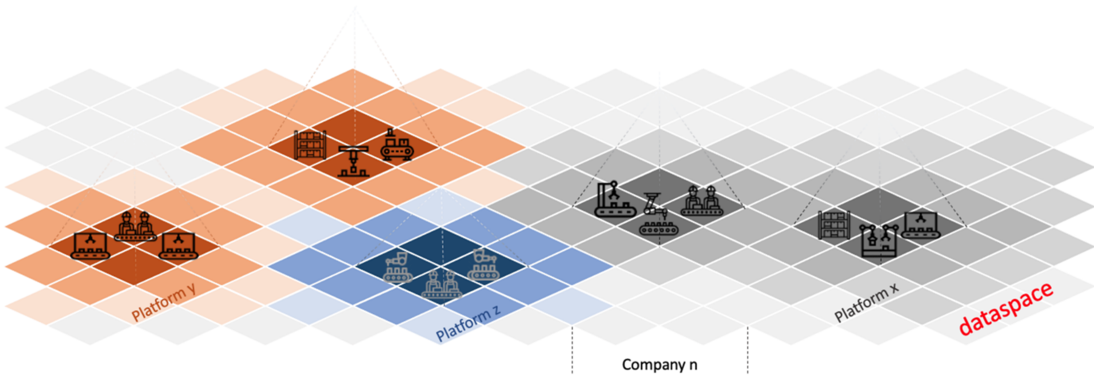

Figure 2. Leveling the data gaps.

A prerequisite is clearly to leverage existing standards and technologies, as well as accepted governance models, to implement a manufacturing platform to facilitate the secure and seamless exchange of manufacturing data, product data, and business data within value networks in a circular-economy-based ecosystem, integrating diverse (also legacy) digital platforms.

The platform is expected to be based on the implementation and exploitation of the International Data Space policy, namely:

- Data sovereignty—the data owner always specifies the terms and conditions of the use of the data provided;
- Decentralized data management—data management remains with the respective data owner, if desired;
- Easy linkage of data—the platform facilitates the integration and usage of data between participants;
- Trust—all participants, data sources, and data services are certified against commonly defined rules;
- Security—data exchange is secure across the entire supply chain, from data creation to data capture and usage.

The future scenario envisions a manufacturing and service network (Figure 3) composed of different companies and actors exploiting diverse manufacturing platforms, both open and proprietary, where the proposed platform supports the network to seamlessly operate on material and data. Those interactions are structured in circular flows, depicting a USE-centric set of relations aiming at providing the required specific product and/or service while optimizing the usage of resources, including materials and energy (also in transports), creating a balanced and sustainable ecosystem.

These are the bases for innovative cross-company business processes for the smart manufacture and delivery of sustainable products/services in a circular economy framework, aiming at:

- Optimizing the value chain action areas: (1) Match supply and personalized demand (promoting customer involvement); (2) Reduce the time–to–market of remanufactured/recycled products; (3) Optimize the resources and processes across companies; (4) Manage and minimize inventories; (5) Improve quality; (6) Increase asset utilization;
- Maximizing the circular economy value drivers: (1) SIMPLIFY: support the simplification of product design and manufacturing; (2) STANDARDIZE: offer standardization to ease data sharing, and identify common design and production patterns that could facilitate repairing and upgrades of product and equipment sharing; (3) SECURITY: guarantee supply assurance identifying where resources are available; (4) SCALE AND SPREAD: optimize the geographical extension of the supply chain considering sustainability elements; (5) SHARED APPROACHES: facilitate the sharing of overcapacity or underutilization of both production equipment, infrastructures, and products, increasing productivity and user value creation; (6) SERVICE: enable the shift from

"buy and own" model to the "pay per use" model for both companies and customers, guaranteeing higher control of processes and products lifecycle to achieve enhanced utilization, recovery, and recycling rates; (7) STEWARDSHIP: support the optimization of the product lifespan considering whether, from the sustainability point of view, life extension through refurbishment and recovery is desirable or recycle is preferable; (8) STREAM: the exchange of wastes, production scraps, discharged materials, and renewable, biodegradable, and recyclable inputs is fostered in the entire value network to substitute non-renewable resources and eliminate the creation of wastes.

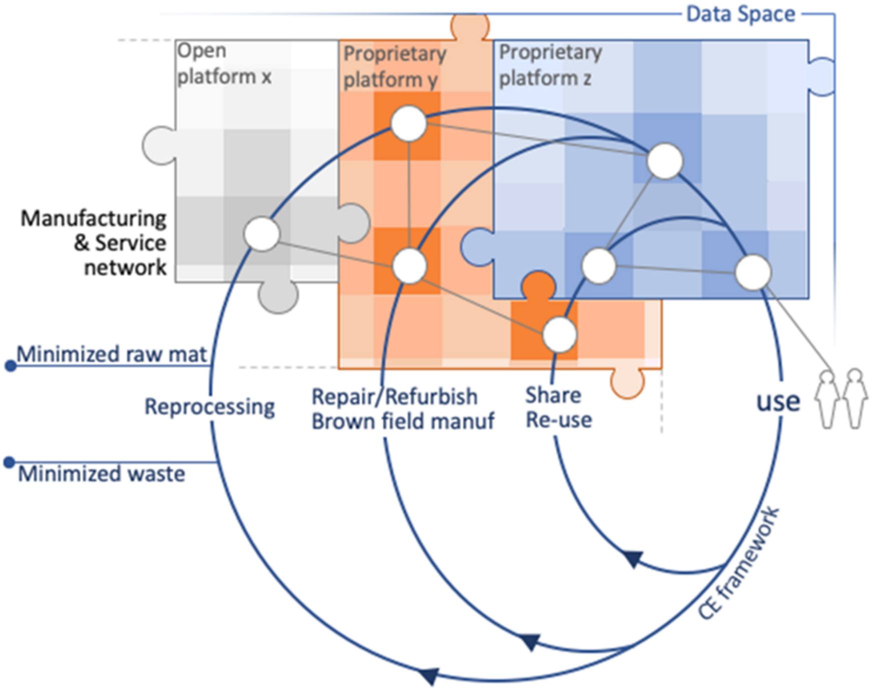

Figure 3. Manufacturing and service network in a circular framework.

4. Technical Solution

According to the European Environmental Agency (EEA) [18] and the UN's Sustainable Development Goals (SDGs) under SDG 12, "Ensure sustainable consumption and production patterns", the transition towards a circular economy requires fundamental changes to production and consumption systems, going well beyond resource efficiency and recycling waste. This paper proposes a conceptual framework for evaluating and managing product circularity from a systemic perspective to empower this shift. This need is clearly highlighted by the EFFRA 2019 vision paper, which calls for "leaving the factory floor" and to look at the bigger picture: the manufacturing ecosystem and how co-creation takes place through the different actors involved. In fact, according to a 2018 report from the World Economic Forum [19], Europe leads the world's smartest factories (seven out of nine selected lighthouse factories). This leadership in Industry 4.0 should be now transformed into digital circular process leadership beyond the factory boundaries. Additionally, the DEI Working Group 2 [20], Strengthening Leadership in Digital Technologies and in Digital Industrial Platforms across Value Chains in all Sectors of the Economy, has, in its more recent report (August 2017) and the October 2018 EC workshop on "Advanced & Interoperable Digital B2B Platforms for Smart Factories and Energy", clearly highlighted that (1) "Big Bang" attempts to launch a new platform for circularity as the preferred solution must be avoided in lighthouse actions; (2) Design should embrace modular software architectures, cross-sectorial workflow automation, and digital twin interoperability; (3) Existing data-driven digital manufacturing platforms should be connected and leveraged through federation under a shared factory 4.0 model that is aligned with and builds upon the RAMI 4.0 (Reference Architecture Model for Industry 4.0) and international open standards (see EFFRA Connected Factories support action); (4) Well-aligned global reference business architectures for a sovereign data economy, such as IDS, and associated open-source reference implementations, such as FIWARE, are highly required for trusted leverage of industrial data value based on the definition and use of common and standardized (converged) APIs and industrial data models should be extensively promoted.

As revealed in October 2018 by the UN report on "Re-thinking production to boost circular economies", the circular economy is not yet being implemented on a large enough scale or at the required pace. Industry extracts over 84 billion tons of materials per year to meet the functional needs of society. Yet, only 9% of these materials are cycled back into our economies [21]. Moreover, remanufacturing accounts for only ~2% of US production, and only ~1.9% of EU production. As part of the Circular Economy Package, the European Commission hopes to provide 580,000 new jobs, reduce greenhouse gas emissions by 450 million tons until 2030, and cut costs of 600 billion euros for European companies, which would be around 8% of its annual turnover and 15% of all the material used in the economy should be recovered and re-used, creating new and lasting competitive advantages for Europe. The transition to a circular economy requires better knowledge about the links between products, their underlying business model, and the societal infrastructure and governance determining their life cycle. However, the circular economy's implementation is primarily a problem of information [22]. So far, a key challenge in this circular process lies in effectively generating, collecting, processing, and making available the volume of information about the material composition/production of each product, use patterns, location within the waste system, etc.

From a software platform perspective, the implementation of a circular economy can be identified mainly as an integration and data management problem that must be addressed with an articulated infrastructure capable of handling the three main phases of (1) data generation, (2) data provision, and (3) data consumption. Indeed, the actors of the circular supply chain must continuously share controlled streams of information related to the product and processes in order to optimize the real material, components, and product flows.

As depicted in Figure 4, this paper proposes a platform that lays its basis upon the synergy between two of the main initiatives dedicated to integration and data management currently available at the European level: IDSA and FIWARE. On the peculiarities of the two reference architectures, the proposed infrastructure is designed to cover all of the key data management processes to ensure an efficient and secure exchange of knowledge among the players of the supply chain.

At the data generation level, the actors of the supply chain must deal with a heterogeneous set of data sources that are different from each other in terms of format, accessibility interfaces, availability, and update frequency. Moreover, once collected, information must be harmonized and aligned, and must undergo the analysis process in order to produce high value-added knowledge.

To this end, this paper proposes whenever possible the adoption of a FIWARE internal data collection and treatment layer. This layer, mainly represented by the Orion Context Broker, allows:

- The integration, on the same data bus, of data streams coming from different sources thanks to the availability of IoT Agents capable of handling several different standard communication formats and mapping them onto a common representation of the process resources;
- The deployment of Data Apps, which are modules providing specific analysis, translation, and knowledge generation algorithms; these apps act as a bridge between the NGSI API of the FIWARE architecture and the security layer of the IDSA Internal Connector (INIC), exposing domain-specific data to the External Connector (EXIC) in a secure and controlled way.

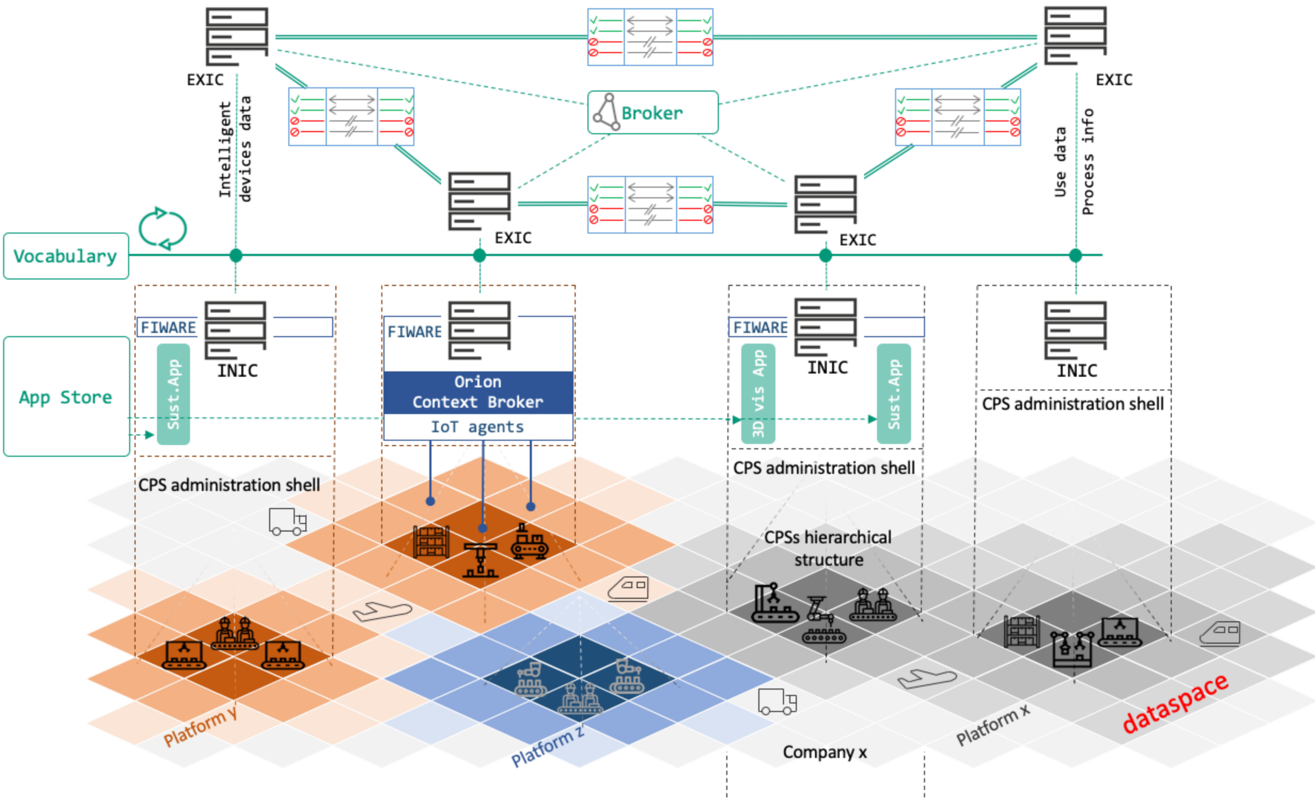

Figure 4. Overview of the proposed platform architecture.

In order to provide a trusted set of Data APPS and in compliance with the IDSA specification, the platform envisions a common AppStore, whose main role is the certification of the Data Apps' behavior so that they can be safely deployed in the internal IT infrastructures of the suppliers. Examples of such data applications are the Sustainability App for the calculation of sustainability indicators, the Data Transformation Apps, whose objective is performing cross-format data translation, and the Big Data Apps for the analysis of big data streams coming from the field and the identification of relevant patterns.

The FIWARE framework and the Data Apps represent the most internal and protected layers of the IDSA Internal Connector (INIC) that are responsible for the projection of each participant into the circular data space it belongs to. In fact, the second main aspect of data management is represented by the Data Provision. This phase requires identifying exactly what information should be shared with the other participants, who should be able to access it, and the expiration of the data in order to satisfy the data sovereignty principle.

For this reason, the proposed platform, referring to the IDSA specification, relies on the adoption of an external connector (EXIC) component that, implementing the authentication and authorization control functionalities, protects access to internal data, providing a subset of information through an efficient p2p connection mediated according to the rules stored in the centralized Broker module. During the initialization of each communication channel, the Broker provides the constraints that must be applied to the transactions and maintains an up-to-date register of the available EXIC endpoints so that, at any moment, a participant of the circular network is capable of discovering and connecting to a required data source. In this way, the Broker supports the third fundamental aspect of data management represented by Data Consumption.

If the Broker and EXIC are the key enablers of the sovereignty principle, the Shared Vocabularies represent the foundations for semantic data exchange, since they contain the common format and data structures that each supplier must use to publish information and consume data. The whole set of information flowing onto the EXIC connections, in fact, must be expressed using neutral and, whenever possible, standard formats, maximizing the interoperability among the suppliers. As previously stated, the component of the architecture devoted to trusted data translation is the Data Apps deployed in the INIC; the management of the Vocabularies is another complementary natural responsibility of the AppStore.

The following potential risks are standing related to the deployment of such platform [23]:

- Being able to understand the requirements of users in terms of content, data encodings, and semantics and granularity is critically important.
- The governance of data in an increasingly complex setting is challenging. How to make the most out of the scattered resources while retaining sovereignty from big software platforms is to be addressed.
- Regulatory aspects that would ensure that all involved actors, such as the private sector and citizens, can contribute, but also benefit from the emerging data spaces should be clarified.

Finally, it is important to highlight that multiple data spaces can occur and co-exist at different territorial levels, which, in turn, would require the elaboration of organizational and technological approaches for coupling the different data spaces in a loose and flexible manner.

5. Conclusions

This paper is meant to lay the basis for a new manufacturing platform meant to "level" the aforementioned gaps, providing a common data space to implement a platform of platforms in a circular economy-based ecosystem.

In more detail, this paper has identified six challenges to be addressed in order to successfully deploy a manufacturing platform to support value networks operating in a circular economy framework. Consequently, it depicts a vision for this platform as an ecosystem of open platforms and commercial solutions meant to "level" the gaps identified, promoting an IDS-based common data space to implement a platform of platforms. Eventually, the paper drafted a technical approach to the actual deployment of the platform.

Author Contributions: Conceptualization, P.P., O.L. and P.M.; methodology, M.S.; software, D.R.; validation, D.R.; formal analysis, M.F.; investigation, M.F.; resources, M.F.; writing—original draft preparation, P.P.; writing—review and editing, M.F. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Meseguer-Sánchez, V.; Gálvez-Sánchez, F.J.; Molina-Moreno, V.; Wandosell-Fernández-De-Bobadilla, G. The Main Research Characteristics of the Development of the Concept of the Circular Economy Concept: A Global Analysis and the Future Agenda. *Front. Environ. Sci.* **2021**, *9*, 304. [CrossRef]
2. Schandl, H.; Fischer-Kowalski, M.; West, J.; Giljum, S.; Dittrich, M.; Eisenmenger, N.; Geschke, A.; Lieber, M.; Wieland, H.P.; Schaffartzik, A.; et al. *Global Material Flows and Resource Productivity: Assessment Report for the UNEP International Resource Panel*; United Nations Environment Programme: Paris, France, 2016.
3. Rodríguez, R.M.; Labella, Á.; Nuñez-Cacho, P.; Molina-Moreno, V.; Martínez, L. A comprehensive minimum cost consensus model for large scale group decision making for circular economy measurement. *Technol. Forecast. Soc. Chang.* **2021**, *175*, 121391. [CrossRef]
4. Waste to Wealth. Available online: https://newsroom.accenture.com/news/the-circular-economy-could-unlock-4-5-trillion-of-economic-growth-finds-new-book-by-accenture.htm (accessed on 10 January 2022).

5. Nasr, N.; Russell, J.; Bringezu, S.; Hellweg, S.; Hilton, B.; Kreiss, C.; Von Gries, N. *Re-defining Value–The Manufacturing Revolution. Remanufacturing, Refurbishment, Repair and Direct Reuse in the Circular Economy*; IRP Report; United Nations Environment Programme: Nairobi, Kenya, 2018.
6. Lacy, P. Using digital tech to spin the circular economy. Accenture Outlook. 2015. Available online: https://www.accenture.com/cr-en/insight-outlook-using-digital-tech-spin (accessed on 10 January 2022).
7. Antikainen, M.; Uusitalo, T.; Kivikytö-Reponen, P. Digitalisation as an enabler of circular economy. *Procedia CIRP* **2018**, *73*, 45–49. [CrossRef]
8. European Commission. Workshop on advanced & Interoperable Digital B2B Platforms for Smart Factories and Energy, 15–16 October 2018, Brussels, Belgium. Available online: https://ec.europa.eu/futurium/en/partnerships-and-digital-industrial-platforms/workshop-advanced-and-interoperable-digital-business.html (accessed on 10 January 2022).
9. EFFRA vision for a manufacturing partnership in horizon Europe 2021–2027, 19 March 2019. Available online: https://www.effra.eu/sites/default/files/190312_effra_roadmapmanufacturingppp_eversion.pdf (accessed on 10 January 2022).
10. The Circularity Gap Report. *World Economic Forum Annual Meeting, Davos, Switzerland*. 2019. Available online: https://assets.website-files.com/5d26d80e8836af2d12ed1269/5dea43f562f8ac3e3113fe51_ad6e59_ba1e4d16c64f44fa94fbd8708eae8e34_compressed.pdf (accessed on 10 January 2022).
11. Dhillon, G. Data Silos are the Greatest Stumbling Block to an Effective Use of Firms' Data. Available online: https://blogs.lse.ac.uk/businessreview/2018/07/25/data-silos-are-the-greatest-stumbling-block-to-an-effective-use-of-firms-data/ (accessed on 10 January 2022).
12. Lu, Y.; Morris, K.C.; Frechette, S. *Current Standards Landscape for Smart Manufacturing Systems*; NISTIR 8107; National Institute of Standards and Technology: Gaithersburg, MD, USA, 2016; 39p. [CrossRef]
13. Barbero, M.; Cocoru, D.; Graux, H.; Hillebrand, A.; Linz, F.; Osimo, D.; Siede, A.; Wauters, P. *Study on Emerging Issues of Data Ownership, Interoperability, (re-) Usability and Access to Data, and Liability*; Publications Office of the European Union: Luxembourg, 2018.
14. Barni, A.; Fontana, A.; Menato, S.; Sorlini, M.; Canetta, L. Exploiting the digital twin in the assessment and optimization of sustainability performances. In Proceedings of the 2018 International Conference on Intelligent Systems (IS), Funchal, Portugal, 25–27 September 2018.
15. Vassakis, K.; Petrakis, E.; Kopanakis, I. Big data analytics: Applications, Prospects and Challenges. In *Mobile Big Data*; Springer: Cham, Switzerland, 2018; pp. 3–20.
16. Opazo-Basáez, M.; Ghulam-Muhammad, S.; Arias-Aranda, D.; Molina-Moreno, V. A roadmap towards smart services in healthcare. *DYNA* **2017**, *92*, 22–27.
17. Manufacturing—2018 CGI Client Global Insights. Available online: https://www.cgi.com/en/media/white-paper/manufacturing-client-global-insights-2018 (accessed on 10 January 2022).
18. European Environment Agency. *Circular by Design-Products in the Circular Economy*; EEA: Copenhagen, Denmark, 2017.
19. Europe, Asia Lead the Way to the Factories of the Future. Available online: https://www.weforum.org/press/2018/09/europe-asia-lead-the-way-to-the-factories-of-the-future/ (accessed on 10 January 2022).
20. Strengthening Leadership in Digital Technologies and in Digital Industrial Platforms across Value Chains in all Sectors of the Economy. Available online: https://ec.europa.eu/futurium/en/system/files/ged/dei_working_group_2_platforms.pdf (accessed on 10 January 2022).
21. De Wit, M.; Hoogzaad, J.; Ramkumar, S.; Friedl, H.; Douma, A. *The Circularity Gap Report: An Analysis of the Circular State of the Global Economy*; Circle Economy: Amsterdam, The Netherlands, 2018.
22. European Commission. Report on the Implementation of the Circular Economy Action Plan. 2017. Available online: https://www.economiecirculaire.org/articles/h/report-on-the-implementation-of-the-circular-economy-action-plan-january-2017.html (accessed on 10 January 2022).
23. Kotsev, A.; Minghini, M.; Tomas, R.; Cetl, V.; Lutz, M. From Spatial Data Infrastructures to Data Spaces—A Technological Perspective on the Evolution of European SDIs. *ISPRS Int. J. Geo-Inf.* **2020**, *9*, 176. [CrossRef]