Analysis of Manufacturing Platforms in the Context of Zero-Defect Process Establishment

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Abstract. The fourth Industrial Revolution sets higher standards for the manufacturing itself and all associated processes. A promising direction in this context is the concept of Zero-Defect Manufacturing (ZDM) aiming at further automatization and optimisation of the production processes to reduce resources and avoid useless elements in the production chains. Moreover, the modern industrial systems are highly complex and require collaboration with other systems for the products' manufacturing and maintenance. This fact leads to the necessity for the better approaches for design, development, evaluation and assessment of manufacturing systems. The goal of this article is to assess some key European research projects on industrial manufacturing to re-use their achievements for design of the ZDM systems. Another goal is to identify the basis for an umbrella platform able to integrate the functionalities of other manufacturing platforms. Thus, interoperability and collaboration issues are also in the scope of this work.

Keywords: Zero Defect Manufacturing · RAMI 4.0 · Industry 4.0 · Systems interoperability · Collaborative Cyber-Physical systems · Business ecosystem

1 Introduction

Technological advancements in recent decades led to a new era of manufacturing or 4th industrial revolution, introducing flexible production processes aligned with the customer's demands [1]. Transition to the new generation of manufacturing systems sets new challenges both at technological and organisational levels [2]. Some of the core challenges are: collaboration, safety and security, standardization, staff training, improved resources use, industrial infrastructure, complexity/cost reduction, real-time coordination and optimisation, interoperability [2–4]. Another important challenge is the digitalisation of manufacturing processes, whereas combining physical and cyber dimensions of industrial systems. Thus, complex industrial systems designed in line with the Industry 4.0 concept are, in fact, complex Cyber Physical Production Systems

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(CPPS) containing collaborative components [2, 5]. CPPS cover the whole conventional automation stack [6]: (i) physics and mechanics of production, (ii) sensing and actuation, (iii) field level control over production process, (iv) execution system, and (v) enterprise resource planning with one additional dimension, namely the inter-systems collaboration [2, 7]. However, the manufacturing processes are not limited to the production itself, but also include the whole product life cycle from design to post-sale maintenance and even recycling.

Industry 4.0 implies production costs reduction, as well as resources use optimisation. This led to emergence of the Zero-Defect Manufacturing (ZDM) strategy. ZDM is directed towards achieving various benefits: lower energy consumption, lower costs, less scrap output, less material waste, production system resilience, improved production status overview, improved planning ability, etc. [8]. Among recent efforts made in line with ZDM strategy we can mention: the “ForZDM” and “ZAero” European projects. ForZDM implements the ZDM strategy through “*combining sensor readouts, visual inspections, or manual measurements at every production stage in a centralized database*” [9]. The proposed platform follows the “state of the art” architecture including the shop-floor layer, cyber layer, and the middleware layer. ZAero on the other hand targets the inline quality control for aerospace parts production merged with decision support systems and simulation [10].

This work is done in the context of providing the basis for the technological and standardization approach for the EU project Zero Defect Manufacturing Platform (ZDMP). ZDMP focuses on both Process and Product quality for pre-, during, supervisory, and postproduction quality issues. ZDMP targets an open Industry 4.0 environment where a new generation of developed zero-defect service applications will be available in a marketplace, contributing to create a collaborative business ecosystem [11] where ZDMP stakeholders would be able to interact with each other.

The remaining of this paper is structured as follows: Sect. 2 gives a brief overview of reference models for manufacturing systems; Sect. 3 discusses the strategy for manufacturing platforms assessment; Sect. 4 proceeds with the analysis of selected projects based on identified topics and discusses standardisation efforts towards ZDM strategy; and finally, Sect. 5 presents some conclusions and directions for further work.

2 Reference Architecture Models for Intelligent Manufacturing

It is very important that designed systems follow some standard or widely recognised architectural approach. In fact, the reference architectures can be used not only for designing new industrial manufacturing systems, but also to assess already developed systems. The use of reference models improves understanding if and how some of the elements of already developed systems can be reused in the newly designed systems considering collaborative and interoperability issues. Several efforts are undertaken towards establishment of common architectural approaches to industrial manufacturing platforms in regard to their functionality, technologies, and organizational structure. Some architectural approaches are of particular interest [12–15], such as: Industrial Internet Reference Architecture (IIRA), International Data Spaces Reference

Architecture (IDS RAM), Intelligent Manufacturing System Architecture (IMSA), Reference Architecture Model for Industry 4.0 (RAMI 4.0), and a Reference model for Collaborative Networks (ARCON) [16]. Some research activities target how the mentioned models can be aligned in terms of layers' concordance. Remarkable works are the joint report of Sino-German Industry 4.0 working group [17] addressing the alignment of IMSA and RAMI 4.0 architectural approaches, or the functional mapping of IIRA and RAMI 4.0 [18].

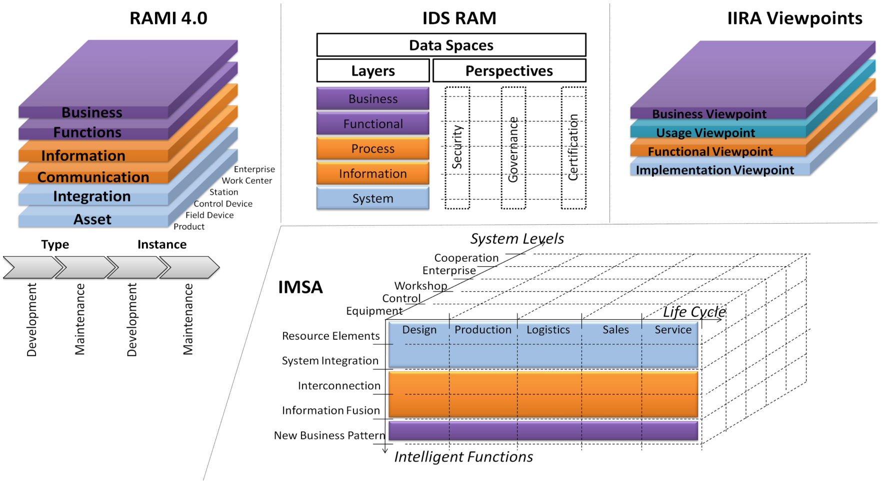

Fig. 1. RAMI 4.0, IIRA, IDS RAM and IMSA architecture approaches.

Figure 1 represents 4 reference models RAMI 4.0, IMSA, IDS RAM, and IIRA, which focus mostly on a single enterprise. For better understanding of layers' alignment and interoperability of different models, same colours are used to mark either completely interoperable system layers (horizontal layers) or layers with same functionality. Thus, Business layer, Business Viewpoint, or New Business Pattern are marked with the same colour; the same logic is applied to other layers.

IIRA is an open architecture for Industrial Information Systems (IIS) based on ISO/IEC/IEEE 42010:2011 standard [19]. The core four viewpoints of IIRA are: (i) Business, (ii) Usage, (iii) Functional, and (iv) Implementation. Business viewpoint serves the goal to assess the system from the business context, i.e. stakeholders' identification, visions, objectives, and high-level representation of how functionalities of the system are meeting the stated objectives. On the Usage layer a set of activities required for providing the system's functionality is presented. The system's structure along with core components, internal relations, and relation patterns with outer elements and systems are in the scope of the Functional layer. The Implementation layer copes with technologies for embodiment of functional blocks, communication schemes, and lifecycles of the designed systems.

The IDS RAM is an architecture aimed at "*generalisation of concepts, functionality, and overall processes involved in the creation of a secure "network of trusted* *data*" [12]. In spite of the fact that IDS RAM is mostly focused on processes around data, including generation, exchange, formats, and licensing, the model can be considered as relevant from the cyber perspective of CPPS. This model also partially follows the ISO 42010 standard and is similar to IIRA offering a common basis for compatibility. This architecture includes five layers: (i) Business, (ii) Functional, (iii) Process, (iv) Information, and (v) System, and three perspectives valid across all layers, that are: (i) Security, (ii) Certification, and (iii) Governance.

IMSA is a three-dimensional model, in some works referred as "Chinese Industry 4.0" [20]. The first dimension reflects the system levels [17]: (i) Equipment, (ii) Control, (iii) Workshop, (iv) Enterprise, and (v) Cooperation. This dimension represents the hierarchy of entities on various scales of production processes. The second dimension – Lifecycle, covers the stages of value creation process [15]: (i) Design, (ii) Production, (iii) Logistics, (iv) Sales, and (v) Services, i.e. form the products design and assembly to the after-sales maintenance. The Intelligent Functions is the third dimension and corresponds to the layers in RAMI 4.0.

RAMI 4.0 is focused on the design and development process of Industry 4.0 systems regarding 3 dimensions: (i) Hierarchy Levels, (ii) Lifecycle, and Value Stream, and (iii) Layers [13]. The Hierarchy Levels dimension follows the IEC 62264 and IEC 61512 standards considering collaboration on the "Connected World" scale and degree of product's involvement on every manufacturing or maintenance stage in "Product" [21]. Other levels are: (i) Enterprise, (ii) Work Centres, (iii) Station, (iv) Control Device, and Field Device (v). The Life Cycle and Value Stream dimension follows the IEC 62890 standard, whereas introducing the differentiation between the "type" – virtual prototype, model, and "instance" – already implemented object or software component, subdivided onto development/and maintenance stages.

The Layers dimension of RAMI 4.0 introduces the building blocks from which the system comprises. There are 6 sub-layers within the "Layers" dimension: (i) Business, (ii) Functional, (iii) Information, (iv) Communication, (v) Integration, and (vi) Asset, covering the whole CPPS stack from machines to high-level business processes.

Although the mentioned models briefly refer to the "collaboration perspective", a core enabler of Industry 4.0 [2], they are mostly focused on the "internals" of a single enterprise. On a completely different direction, ARCON [16, 22] is focused on collaborative networks, thus better addressing the value chain perspective and distributed manufacturing systems. ARCON considers 3 main dimensions (Fig. 2): (i) Life-cycle, (ii), Environment characteristics, and (iii) Modelling intent. The environment characteristics include the Endogenous Elements of the CN (E1- Structural, E2- Componential, E3- Functional, E4- Behavioural) and the Exogenous Interactions of the CN (I1-Market, I2- Support, I3- Societal, I4-Constituency).

3 Strategy for Manufacturing Platforms Assessment

The analysis of current manufacturing initiatives and projects can give a good indication for the establishment of the manufacturing platforms assessment strategy, allowing getting the best practices, as well as avoiding unnecessary efforts to develop components from the scratch. Moreover, the marketplace being developed within the

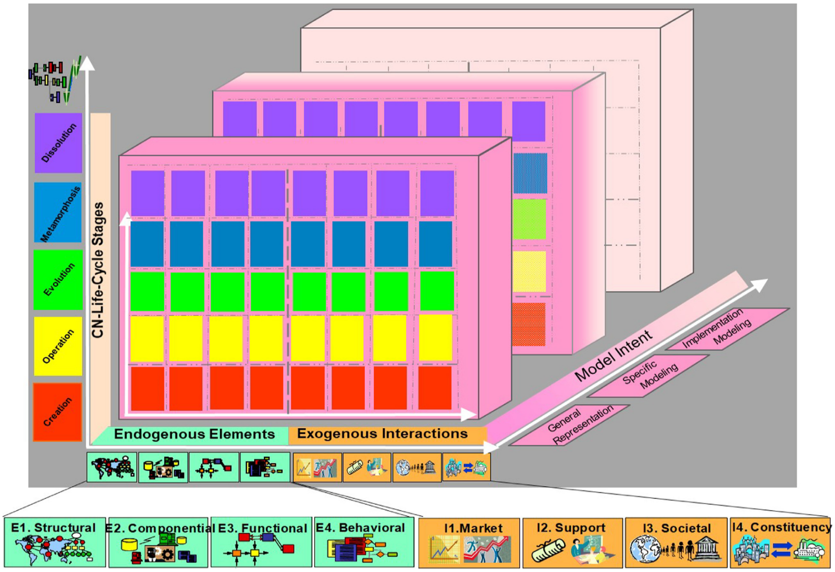

Fig. 2. ARCON reference model framework for collaborative networks (based on [16]).

ZDMP project can benefit from collaboration with other manufacturing platforms and services. This may enrich the marketplace and create a kind of "umbrella" platform, integrating the European efforts towards intelligent manufacturing systems. As ZDMP follows the RAMI 4.0 architectural approach, the studied manufacturing platforms were analysed using the same reference model in order to have a common basis, which is crucial for compatibility and interoperability of the ZDMP platform with other manufacturing platforms. To summarise the efforts undertaken to fulfil the stated goals, the high-level vision of the steps required is introduced:

The methodology to analyse deliverables of manufacturing research projects in order to establish the manufacturing platforms assessment strategy has three stages: Alignment, Analysis, and Estimation (Fig. 3). At the first stage the requirements and goals are identified and set, followed by the focus points such as security, privacy, application/user metadata, underlying technologies, and licensing. The second stage presumes the application of RAMI 4.0 architectural framework to the analysed projects in order to identify which components of the manufacturing platforms are covering the previously mentioned focus points and how they are addressed, in other words, what technologies and approaches are used. During the last stage the important goal is to understand how the identified technologies suit the focus points and how they are compatible (Layers in RAMI 4.0) with the ZDMP platform being developed. A final task is to develop a strategy or a common approach for integration/adoption of manufacturing applications into the common ecosystem. It is important to mention that this particular work is mostly focused on second stage that is Analysis.

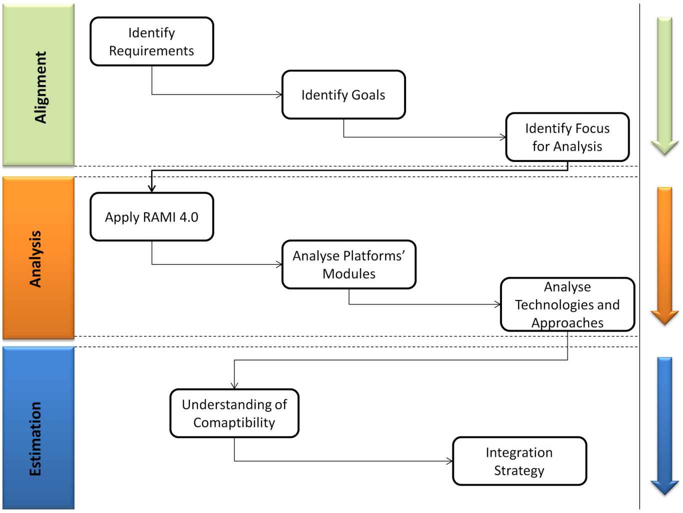

Fig. 3. High-level vision of platforms assessment strategy

4 Manufacturing Platforms Assessment Results and Discussion

The architectural approaches described in the second section serve the purpose of common understanding of standards, technologies, protocols and use-cases. System design by following one of the mentioned architectural approaches should simplify further collaboration, enable the modular system composition and contribute to interoperability. This means that required functionality can be delivered on demand without requiring enormous efforts to align blocks developed in different platforms but following the same approach.

For this work the RAMI 4.0 was chosen, based on various reasons: (i) RAMI 4.0 is compatible with other reference models, (ii) some analysed projects already follow this methodology, as for instance BEinCPPS [23], (iii) ZDMP project is making use of the RAMI 4.0 [13], (iv) RAMI 4.0 is compatible with OSI and Internet Protocol Stack Model (Fig. 4), (v) RAMI 4.0 improves the collective understanding of standards and use-cases in the context of Industry 4.0. It helps to map manufacturing requirements with standards to facilitate development of Industry 4.0 related products. Moreover, RAMI 4.0 specifies the Asset Administration Shell (AAS) [29] that is a digital shell of the physical asset containing all data for linking the assets together and with digital platform. In its turn, the AAS is used to describe the digital dimension of the physical Asset in a standardized way.

Since the work is focused mostly on inside the manufacturing company, and not on networked enterprises, this option is reasonable instead of a more collaboration-oriented model such as ARCON. In terms of compatibility with RAMI 4.0, the Endogenous and to some extent Exogenous elements of ARCON are close to the Layers and Hierarchy Levels of RAMI 4.0. The Life Cycles in both models represent

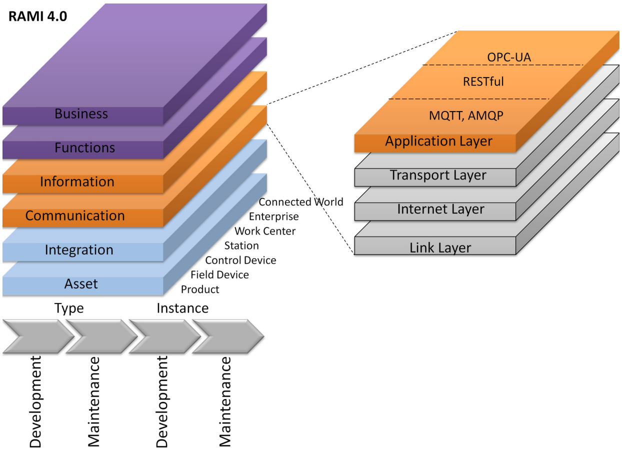

Fig. 4. RAMI 4.0, internet protocol stack and RAMI 4.0 communication layer.

the stages of a product or a system life time. The RAMI 4.0 also presumes some space for collaboration within the Hierarchy Levels, on the last level “Connected World”, although less elaborated than in ARCON. In this particular work, platforms are analysed individually to establish a technological foundation for platforms integration. This is also justified by the fact that the ZDMP project is a member of 4DMP cluster interlinking several ongoing projects in the area of digital manufacturing: ZDMP, QUALITY, EFPF, Kyklos 4.0, digiPRIME and SHOP4CF. Thus, the main goal is to analyse innovative manufacturing platforms to establish the interoperability within 4DMP cluster. The core focus layers of the RAMI 4.0 considered in this work are Information and Communication layers for their particular importance for the AAS. The following aspects are in focus: security, privacy, user and application metadata and underlying technologies, as well as licensing issues.

The inter-platform linking and interoperability with external platforms is essential in the context of reusing deliverables of projects from the area of Internet of Things and CPPS. The following research projects are considered in this study: vf-OS, Disrupt, MANTIS, CREMA, BEinCPPS, I-BiDaaS, DIGICOR, RestAssured, GO0DMAN. One of the main goals of the 4DMP cluster is to establish a fundament for integration of some functionality/services developed within various European research projects; in a later phase also interlinking to commercial platforms is targeted. Thus, understanding of underlying communication basis is important for the establishment of interfaces for integration of different modules. To give the common basis for interoperability assessment, the RAMI 4.0 model is applied to the platforms’ architectures.

In Fig. 5 the architectures of vf-OS, BiDaaS and RestAssured are analysed and the functional blocks responsible for “Information” and “Communication” layers are identified. The black arrows point on the blocks that correspond to “Information” layer and the red arrows to blocks belonging to the “Communication” layers. Thus, system integrators having a look on these blocks can develop a high-level strategy on interoperability opportunities and difficulties. After this step, every block can be zoomed in and analysed in detail with all corresponding technologies, approaches, and protocols that are used, which will result in a set of concrete steps for building the integration middleware.

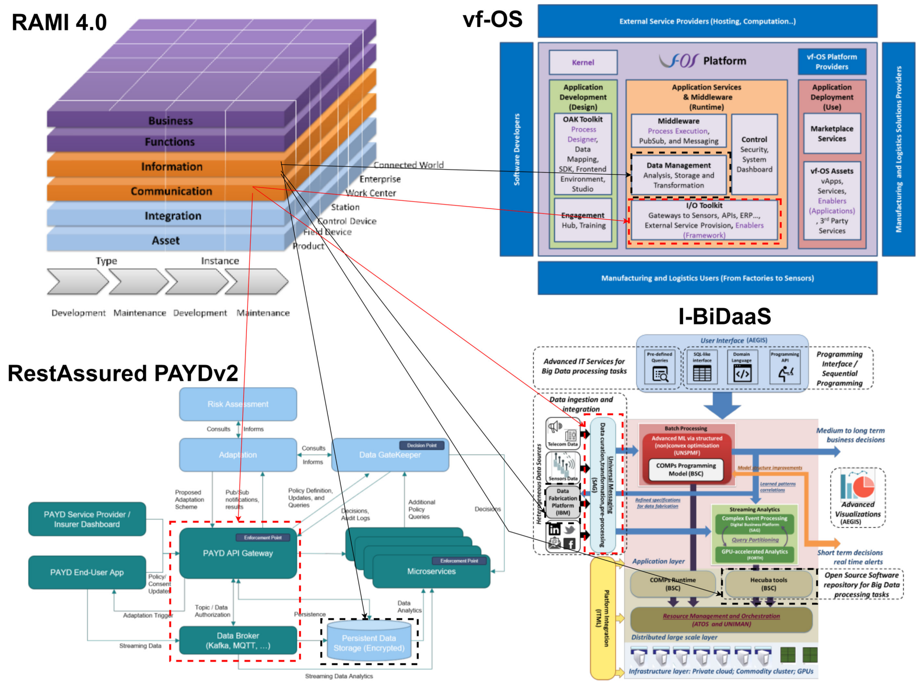

Fig. 5. RAMI 4.0 applied to I-BiDaaS, Restassured and vf-OS architectures

Table 1 presents an analysis of the above motioned projects based on 5 core aspects: security, privacy, licensing, and App/User data with underlying technologies. On its turn, each aspect contains several analysis points that are important for establishing the vision of how various platforms can be combined within one marketplace either directly, by inclusion of functional blocks or through linking the corresponding platform. The inputs for the table are based on the public available deliverables form those projects. Thus, some information might be not available for the public; if no data is available the table's cell contains the "no details" label.

Most of the reviewed projects use two communication paradigms: the Restful and the Publish/Subscribe. The restful approach follows the classical client-server architecture utilising basic HTTP methods: GET, PUT, POST and DELETE. At the same time, using the publish/subscribe approach allows implementation of the asynchronous messaging which is useful in communication with edge devices [24]. The main messaging protocols are AMQP and MQTT requiring a broker to ensure the asynchronous communication when publisher and subscriber do not need to be available at the same time, but the broker guarantees the message delivery.

Table 1. Analysis of manufacturing projects against identified aspects

Technical Level zApps (high-level)										
GO0DMAN [45,46]	**RestAssured [37,38]**	**DIGICOR [41,42]**	**I-BiDaaS [43,44]**	**BEinCPPS [23, 31]**	**CREMA [3233]**	**MANTIS [34,35]**	**Disrupt [39,40]**	**vf-OS [26,36]**		
JSON	JSON	JSON	JSON	JSON	JSON	JSON	JSON	JSON	**Data Format (Messages)**	**App/User data (underlying technologies)**
MQTT, OPC-UA	*no details*	MQTT, OPC-UA, AMQP	MQTT	MQTT, OPC-UA, AMQP	AMQP	AMQP	MQTT, JMS	AMQP	**Protocols (Messaging)**	
available	*no details*	AmazonMQ	available	RabbitMQ	Apache ActiveMQ	RabbitMQ	available	RabbitMQ	**Message Broker**	
SOA	SOA	SOA	SOA	SOA	SOA	SOA	SOA	SOA	**Architecture**	
Pub/Sub, Restful	Pub/Sub, Restful	Pub/Sub, Restful	Publish/Subscribe, Restful	Pub/Sub, Restful	Pub/Sub, Restful	Pub/Sub, Restful	Pub/Sub, Restful	Pub/Sub, Restful	**Communication Paradigm, API**	
no details	yes	yes	*no details*	*no details*	yes	yes	*no details*	yes	**Docker services**	
no details	MySQL/MariaDB	*no details*	Cassandra/ Hecuba	*no details*	MongoDB, Sesame	Cassandra, Apache Hadoop	Cassandra	MongoDB, ZooKeeper	**Storage**	
no details	yes (IBM)	Yes (OPC UA Server)	Format Preserving Encryption (FPE), Order	yes	yes	Yes (EEBus)	*no details*	yes (KeyRock)	**Encryption**	**Security**
no details	yes	SSL/TLS	yes (SSL)	Optional (SSL)	yes (SSL)	yes	*no details*	Yes (TLS/SSL)	**Data Integrity**	
no details	Keycloack	yes	yes	Yes (OAuth protocol)	yes (security token)	Yes (PAP, Oauth 2.0)	yes	yes (security token)	**Identity Management**	
no details	Keycloack (Kebreros)	yes	yes	yes	yes (login, password)	yes (RFC 4949)	yes	Fiware KeyRock	**Authentication**	
no details	JWT token introspection	yes	yes	*no details*	*no details*	yes	yes	Fiware KeyRock	**Data Confidentiality**	**Privacy**
no details	*CBAC (context based AC)*	RBAC/ ABAC	RBAC	RBAC	RBAC	RBAC/ABAC (attribute based)	RBAC	RBAC (Role based AC)	**Access control**	
Freeware/ Proprietary	Apache License 2.0/ Proprietary	no details	GNU Public Licence/ Proprietary	Apache License v2/ Proprietary	Apache L v2, AGPL, LGPL	no details	Apache License v2	Apache License v2/Proprietary	**Licensing**	
no	no	yes	no	no	yes	no	yes	yes	**Marketplace**	

The commonly used format for the payload in MQTT is JSON, especially in the edge layer, including fetching sensor data. The combination of these paradigms allows to use the Restful approach to communicate with end applications and messaging middleware [25] to act as a bridge between the edge devices and end applications, as well as for inter-component communication within the platform. However, the de-facto standard communication approach for the marketplace considering the analysed projects is the RESTful one, mostly using JSON documents for transmitting the user and application metadata or even security related data.

For storage both SQL and NoSQL approaches are widely used. Examples are MongoDB – a document-oriented NoSQL DB enabling storage of JSON documents, Apache Zookeper – a NoSQL database for storing the key-value pairs, Sesame for storing the RDF triples, but also conventional SQL databases, such as MySQL. It is hard to identify a common approach regarding storage tools selection, as it largely depends on the particular type, context, and form of the stored data. For instance, vf-OS is based on the polyglot persistence paradigm [24] combining various DB types in order to utilize different DBs to the best of their potential. An example is the user or application related data which are sent as JSON documents and stored in MongoDB without a need for excessive Extract Transform Load (ETL) operations.

Docker containers are wildly used to enable encapsulation of components as services to be further exposed as software packages [26]. This fact is related to the growing trend to "*move from the monolithic software architecture where many components of a software system run in a single process*" [27]. Docker is a platform used to run applications as a set of containers at the same time on the same host. This means that the functional blocks of the system are composed of many small services delivered as containers [28].

The analysis made shows that various projects are using their own developed security and privacy tools. Just a few utilize third-party solutions such as KeyRock Fiware Generic Enabler or the Keycloak. KeyRock, used in vf-OS, is based on OAuth 2.0 protocol supporting basic authorisation, encryption, authentication and data confidentiality. This protocol supports the Identity Management using "security tokens" that are issued to the client to access protected resources. Security tokens contain all the necessary data about the client, issuing entity and the lifetime of the token. Keycloak on its turn supports both the OAuth 2.0 protocol and the Security Assertion Markup Language (SAML 2.0). Integrity and Encryption are usually assured using the Transport Layer Security (TLS) or Secure Sockets Layer (SSL), used by the majority of the analysed projects. As for the access control, the mostly used approach is the Role Based Access Control (RBAC), in some cases in conjunction with Attribute Based (ABAC) and in one case with Context Based (CBAC). The RBAC approach is based on roles and privileges mechanism, where every user acquires a role to access resources, whereas CBAC is used for traffic filtering and in ABAC access rights are provided through policies combining Boolean attributes.

Most of the technologies and third-party services used in the projects are open source or community editions of commercial software. However, some manufacturing partners might insist on making some parts of the platform available against a fee and thus distributed under proprietary licenses. Sometimes the project goals require utilization of proprietary software, so the resulting platform includes the fee of this component. However, most solutions follow the Apache 2.0 licence, e.g. Keycloak, Cassandra, Hadoop or GNU Public Licence as MySQL or MariaDB. However, a marketplace encapsulating several platforms should be able to cope with multiply licenses.

Whereas implementing the assessment, several limitations were identified, as for instance, integration of platforms and solutions provided by third-parties due to different interfaces, data formats and licensing schemas used. An illustrative example here is the fact that there are more than 25 available vendor-specific industrial Ethernet protocols [30]. These difficulties appear during the Estimation stage of the assessment. An additional difficulty can be the fact that the same functional block in the platform architecture can be aligned with several Layers of the RAMI 4.0 fulfilling the tasks from several layers. An additional challenge can be further alignment of the functional block with the Hierarchy Levels and Life Cycle dimensions of the RAMi 4.0, whereas the current work's focus was on only one dimension – Layers.

5 Conclusions and Further Work

The fourth industrial revolution sets new challenges for design and development of manufacturing systems and platforms. One of those challenges is the strategy of Zero-Defect Manufacturing focusing on improving and optimising the production processes. This can be accomplished in various ways such as defects prediction, production optimisation using intelligent algorithms, strict measures to control the production flow, etc. The European ZDMP initiative aims at implementing this strategy through development of novel manufacturing applications, but also to establish a marketplace for encapsulation of manufacturing applications developed within other European manufacturing research projects and thus enrich the production ecosystem.

In this work we introduced the approach for analysis of European projects based on predefined focus points such as security, privacy, data and communication solutions, and licensing, whereas using RAMI 4.0 architectural approach as the basis. Moreover, issues of compatibility of RAMI 4.0 with other up to date reference models were also in the scope of the work. The strategy for assessment of the digital manufacturing platforms developed within several European projects such as vf-OS, Disrupt, MANTIS, CREMA, BEinCPPS, I-BiDaaS, DIGICOR, RestAssured, GO0DMAN, was proposed. It consists of three phases Alignment, Analysis, and Estimation, whereas the current work was mostly focused on the Analysis stage. During the assessment process, several limitations and challenges were identified: proprietary solutions even based on well standardised protocols and approaches, some platform functional blocks can be aligned with several RAMI 4.0 Layers, some assessment points, for instance, "Data Format" are not enough for deeper analysis, as they only state the syntax used (JSON), without giving an insight on the corresponding semantics and structure. Furthermore, the results of the assessment and analysis base on identified criteria were presented.

Further work will require efforts towards the Estimation phase of the methodology to finalise the analysis of the manufacturing platforms and choose the proper strategy for establishing the interoperability among the marketplaces of the manufacturing platforms and integrate manufacturing applications into the ZDMP marketplace.

Moreover, alignment of the assessed platforms with other 2 dimensions of the RAMI 4.0 – Hierarchy Levels and Life Cycle, can be considered as a part of future work.

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