

# Cloud Computing, Big Data and the Industry 4.0 Reference Architectures

## Cloud Computing, Big Data y las Arquitecturas de Referencia de la Industria 4.0

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### Abstract

The Industry 4.0 promotes the use of Information and Communication Technologies (ICT) in manufacturing processes to obtain customized products satisfying demanding needs of new consumers. The Industry 4.0 approach transforms the traditional pyramid model of automation to a network model of interconnected services, combining operational technology (OT) with Information Technology (IT). This new model allows the creation of ecosystems enabling more flexible production processes through connecting systems and sharing data. In this context, cloud computing and big data are critical technologies for leveraging the approach. Thus, this paper analyzes cloud computing and big data under the lenses of two leading reference architectures for implementing Industry 4.0: 1) the Industrial Internet Reference Architecture (IIRA), and 2) the Reference Architecture Model Industrie 4.0 (RAMI 4.0). A main contribution of this paper is to present a comparative analysis of IIRA and RAMI 4.0, discussing needs, benefits, and challenges of applying cloud computing and big data in the Industry 4.0.

**Keywords:** Big Data, Cloud Computing, Industry 4.0, Industrial Internet Reference Architecture (IIRA), Reference Architecture Model Industrie 4.0 (RAMI 4.0).

### Resumen

La Industria 4.0 promueve el uso de las Tecnologías de la Información y la Comunicación (TIC) en los procesos de fabricación para obtener productos personalizados que satisfagan las necesidades más exigentes de los nuevos consumidores. El enfoque de Industria 4.0 transforma el modelo tradicional piramidal de automatización en un modelo de red de servicios interconectados, combinando la tecnología operacional (OT, en inglés) con la tecnología de la información (TI). Este nuevo modelo permite la creación de ecosistemas para hacer el proceso de producción más flexible mediante la conexión de sistemas y el intercambio de datos. En este contexto, la computación en la nube y el big data (grandes volúmenes de datos) son tecnologías fundamentales para implementar la Industria 4.0. Por lo tanto, este documento analiza la computación en la nube y grandes volúmenes de datos bajo las lentes de dos arquitecturas de referencia líderes para la implementación de Industria 4.0: 1) la Arquitectura de Referencia de Internet Industrial (IIRA), y 2) el Modelo de Arquitectura de Referencia Industrie 4.0 (RAMI 4.0). La contribución principal de este artículo es presentar una guía comparativa de IIRA y RAMI 4.0 y discutir las necesidades, los beneficios y los desafíos de la aplicación de computación en la nube y grandes volúmenes de datos en Industria 4.0.

**Palabras clave:** Arquitectura de Referencia para el Internet Industrial (IIRA), Big Data, Cloud Computing, Industria 4.0, Modelo de Arquitectura de Referencia para la Industria 4.0 (RAMI 4.0).

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### 1. Introduction

Industry 4.0 (I4.0) is a term coined in Germany, also referred as the Fourth Industrial Revolution. The first revolution was marked by the use of the steam engine, the second by the electric power and the third by electronics. Each one generated main

changes in the form and means applied in production processes, as well as in society. The fourth industrial revolution is characterized by incorporating information technology into production processes to digitize components and elements involved in the manufacturing, and joining Operations Technology (OT) with Information Technology (IT). The approach allows machines to communicate with machines and the usage of customer's data in the production process, enabling the customization of products. In addition, there is a total traceability of the product manufacturing process. The fourth industrial revolution facilitates that components and production machines are operated autonomously and efficiently. It facilitates means to communicate machines and people regardless of their location and enables interactions from multiple devices. Through such communication, suppliers, producers and consumers are able to access and analyze together data about products and their production processes.

Considering the importance of adopting new ICT-enabled production methods for industries, there are currently reference architectures that facilitate their adoption and continuous evolution [1]. For example, in Germany, the Reference Architecture Management Industrial 4.0 (RAMI 4.0) is published through the project called *Plattform Industrie 4.0*. The project aims at the development and implementation of the Industry 4.0 as a strategy promoted by the German Federal Government. The initiative is also related to projects in USA, Japan, France and China, among other countries [2]. Due to the government impulse, RAMI 4.0 has now become the German standard DIN SPEC 91345 [3]. In the United States, companies such as General Electric, AT&T, Cisco, IBM and Intel founded the Industrial Internet Consortium (IIC) with the aim of promoting the implementation of the Industrial Internet for the interconnection of machines and devices through the reference architecture called Industrial Internet Reference Architecture (IIRA) [4].

The main objective of the reference architectures IIRA and RAMI 4.0 is to digitize the manufacturing processes, to equip them with "intelligence" through the use of technology. Thus, the aim is to enable major changes in the current production model [5], optimizing the manufacturing processes, reducing costs, elaborating personalized products, focusing on customer-oriented services, and strengthening industries. It is expected that such changes will contribute as a factor of economic growth, employment generation, and creator of ecosystems integrating suppliers and customers [6].

This article presents a comparative analysis between the IIRA and RAMI 4.0 reference architectures, considering their approach and constitutive elements and how they contribute to the understanding and implementation of the Industry 4.0, particularly, in Small and Medium enterprises (SMEs). The focus on SMEs is based on the feature that they are generally suppliers of large companies

and may lack qualified personnel specialized in Industry 4.0 approach.

The rest of –this paper is organized as follows. Section 2 presents a brief summary of the fundamentals of Industry 4.0, cloud computing and big data, as technological enablers. Section 3 explains the reference architectures *RAMI 4.0* from Germany, and *IIRA* from the United States. Following, Section 4 compares the approaches and constitutive elements of the two models. Finally, challenges, opportunities, and future research work are discussed in Section 5.

## 2. Background

Industry 4.0 transforms the traditional production process following a pyramidal structure based on the ISA 99/IEC 62443 standard towards a networked model, totally interconnected through the Internet of Things (IoT) [7]. The new approach enables more flexible production processes according to new demands on optimization of resources, cost reduction and establishment of effective communication between customers, industry and suppliers [8]. It incorporates the benefits of IT through the so-called technological enablers such as: simulation, artificial intelligence, collaborative robotics, virtual and augmented reality, cybersecurity, vertical and horizontal integration, 3D printing, cloud computing and big data. Applying a combination of them enables new processes, new products, new business models [9].

Additionally, the current technological development allows the supply for even smaller electronic components, with greater capacity and at lower cost, and facilitates the incorporation of sensors in products and machines. This feature affects the production process, the product and the business model. In particular, the incorporation of technological enablers to the product development process gives intelligence to the process and enables to obtain information from the different process phases, such as: design (from the original idea), manufacturing (life cycle), logistics, distribution, delivery and after sale. Likewise, it allows to include the specifications of the product requested by the client during the design phase, enabling to obtain a customized product. This later alternative enables to perform the design in a collaborative way regardless the physical location of the design members. It also allows to conduct simulations of the resulting product before going to production phase, enabling to plan the production process in a flexible manner, coordinating response times according to the products to be manufactured, and allowing collaborative production in different geographical locations [10].

Similarly, the Industry 4.0 promotes full traceability of the product life cycle, horizontal and vertical integration of software applications. It allows having real-time information for timely

decision-making, including information for autonomous decision-making without human participation, having transparent information throughout the production process, detecting errors in manufacturing and returning immediately the product to correct them, and detecting possible failures to act preventively.

Finally, the approach also allows planning preventive maintenance, monitoring the process remotely to avoid cuts in production due to equipment failure, planning manufacturing at different points regardless of geographical location, facilitating communication with different suppliers throughout the process, reducing stocks and delivery times, obtaining information on the use and life of the product and having information to generate new business models.

The "hyper-connectivity" of the various systems involved in the production process, on which Industry 4.0 is based, multiplies the data generated in real time from different sources and varied formats that must be stored and analyzed with technologies and advanced algorithms. For such reasons, cloud computing and big data are two major technologies applied by the approach. Both are considered fundamental requirements for Industry 4.0, providing relevant and necessary components for the implementation of the approach [11]. The relationship between these two enablers and Industry 4.0 is presented in Fig. 1.

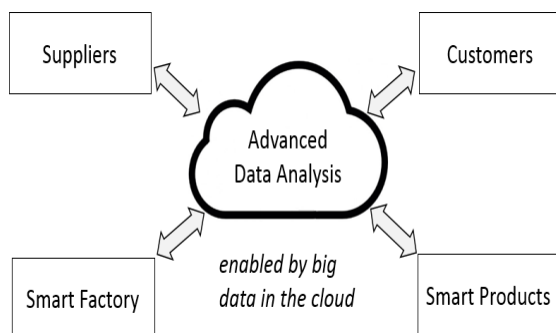


Fig. 1 Cloud Computing, Big Data, and Industry 4.0

### 2.1. Technological Enabler: Cloud Computing

Cloud Computing allows the storage of large amounts of data. This capacity is mainly important to store the data generated during a whole production process, considering that the machines and sensors produce more data than a person and such data is always connected. Likewise, cloud computing reduces investment in technological resources, allowing the storage space and processing capacity to be contracted on demand, which provides flexibility, agility and adaptability [12]. Through a scalable structure, the cloud allows the consumption of resources on request. This enables to reduce costs, since it avoids purchasing servers, licenses, and hiring specialized personnel for

maintenance, as well as to save energy. In addition, it provides ease of access to storage from different geographical points, and different schedules, regardless of the platform and connecting devices. All this, facilitates the creation of manufacturing ecosystems and encourages collaboration between customers and suppliers. In particular, the customer can participate in all stages of the production process and therefore their satisfaction is improved.

Due to the large volumes of data processed in the cloud, there is latency time that can affect the performance of the production process. To solve this problem, it is possible to use "Fog Computing". Fog computing refers to the processing capacity for data analysis and control functions based on large volumes of data received by Internet of Things (IoT) devices. The nodes that perform such processing are usually located in the same local network as the IoT devices, and, usually, they have storage and computing capacity. Thus, fog computing, compared to cloud computing, decreases instability, avoids congestion and improves quality of service [10]. Additionally, to strengthening the security and privacy of data, it enables implementing private clouds for the exclusive use of industries that need extreme confidentiality.

The ISO/IEC JTC 1/SC 38 Committee (IEC 19944) is responsible for the standardization of cloud computing [13], and provides models and standards for small and medium-sized enterprises (SMEs).

### 2.2. Technological Enabler: Big Data

Big Data techniques allow to analyze enormous volume of information that is generated in an Industry 4.0 production ecosystem. Techniques such as advanced, historical, predictive and descriptive analysis [14] enables to assess the state and operation of the machines involved in production processes, control and monitoring. The analysis of data for predictive maintenance reduces inefficiencies and costs, anticipating equipment failures and allowing better responses to emergent and remote situations caused by different factors such as bad weather, high humidity, high temperature, exposure to gases, etc.

As another example, predictive analysis also allows the control of routes determining where disturbances are generated or there is a poor state of the roads. It also allows to determine patterns and correlate data for the improvement of industrial processes, make decisions in real time for operational efficiency, define new business models based on customer behavior, design new services associated with existing products and machine learning [15]. In summary, big data techniques allow generating value to the production chain based on the intelligent use of data.

The use of big data does not depend on the size of the industry. It depends on the business strategy that focuses on taking advantage of the data to improve the manufacturing process and determine the products that the market should produce to satisfy customer's demands. This allows changing the current way in which the company investigates, analyzes and decides the product to be released to the market, increasing the chances that the product will be sold successfully. Also, another important application area of big data is related to security, for analysis and correlation of data to detect fraud, and performing analysis of customer's behavior, smart grids, cyber physical systems (CPS) [16], etc.

Given the relevance of big data for Industry 4.0, the ISO/IEC JTC 1/WG 9 Committee is developing the standard for its application in this context [13].

### 3. Industry 4.0 Reference Architectures

Worldwide there are efforts to implement Industry 4.0. To support these efforts, there are two important reference architectures - the Reference Architecture Model for Industry 4.0 (RAMI 4.0), and the Industrial Internet Reference Architecture (IIRA). In most European countries they have taken RAMI 4.0 as the basis for their production and economic development programs. IIRA is widely deployed because of its origin, the United States, and its permanence in the market. Additionally, China has also a model for its "Made in China 2015" program and Japan with Robot Revolution Initiative. Based on their level of incidence and relevance, RAMI 4.0 and IIRA are analyzed in the following two sections as the main reference architecture models for Industry 4.0.

#### 3.1. IIRA

The Industrial Internet Reference Architecture (IIRA) is a standards based open architecture for Industrial Internet of Things (IIoT) systems, is generic and described with a high level of abstraction. Conceptually it is based on the international standard ISO / IEC / IEEE 42010: 2011 and can be used as an architectural template to define, develop, document, communicate deployment and significantly enhance the interoperability of industrial sectors such as: energy, healthcare, manufacturing, public domain and transportation [17]. This architecture is composed of four levels called **viewpoints**: 1) *Business viewpoint* - identifies stakeholders and their business vision, values and objectives that the IIoT system must comply, considering the business perspective; 2) *Usage viewpoint* - considers whether the expected usage of the IIoT system is described to meet the business objectives; 3) *Functional viewpoint* - comprises the functional requirements of the IIoT system. It is divided into five domains: a) control, b) operations, c) information, d) application,

and e) business; and 4) *Implementation viewpoint* - refers to the technical aspects and technologies that allow implementing the IIoT system according to information of other viewpoints. The viewpoints are related to each other: 1) from the top to the bottom - the information of the Business viewpoint serves as a guide to establish the usage of the IIoT system. Based on the Usage viewpoint, the functionality of the IIoT system is defined; and with the information of the higher viewpoints, the IIoT system is implemented; 2) from the bottom to the top - the Implementation viewpoint enables to validate and check that the requirements of the Functional, Usage and Business viewpoints are met.

IIRA defines the functional domains to establish how the IIoT system should work and includes a set of cross-cutting functions, such as: connectivity, distributed data management and integration, and industrial analytics. Additionally, it determines the following system characteristics: safety, reliability, resilience, privacy and scalability for a good functioning of the system (see Fig. 2).

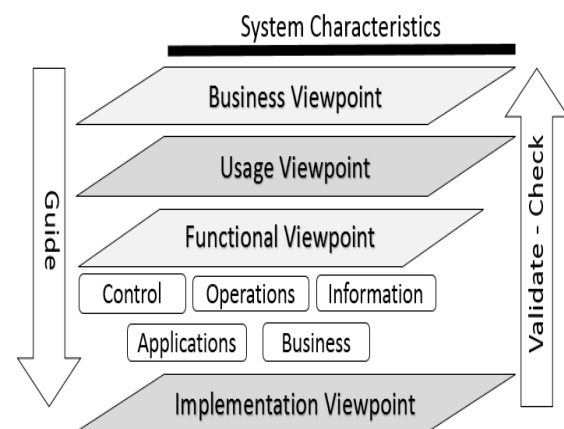


Fig. 2 IIRA Viewpoints and Domains

#### 3.2. RAMI 4.0

The *Reference Architecture Model Industrie 4.0* (RAMI 4.0) is the German standard DIN SPEC 91345:2016-04. The RAMI 4.0 architecture combines aspects related to the manufacturing process, the product, and IT through a three-dimensional hierarchical structure oriented to the service. RAMI 4.0 is a network of components interconnected all together by the "Administration Shell" that contains the data of the virtual representation of a real-world object with its own characteristics and functionalities [18].

In this three-dimensional architecture, the Axis 1 is Hierarchy - represents the new Factory and is based on the IEC 62264/IEC 61512 standard. This axis comprises: the smart products, the Smart Factory and the connected world. The Smart Factory is divided into: field device, control device, station, work centers, and enterprise. The Axis 2 is Architecture - relates to IT and includes six levels:

1) Asset, 2) Integration, 3) Communication, 4) Information, 5) Functional and 6) Business. The Asset level represents the physical things in the real world, the Integration level is the nexus between the real world and the digital world, digitally represents the assets. The following four levels correspond to the digital world [19]: the Communication level enables communicate services and events / data to the upper layer, and services and control to the lower layer. The Information level comprises services and data related to the technical functionality of the asset and the batch in real time. The Functional level contains information on the functions of the asset describing the logical and technical functions of an asset and the platform for integration with other assets. Finally, the Business level contains all the information related to the organization, business processes, legal and regulatory aspects. Resuming, Axis 3 is *Life Cycle and Value Stream* - describes the development of the product from the original idea to become a scrap. It is based on the international standard IEC 62890. The later Axis includes the type and the instance. The type contains the development phase, and the instance covers the production and maintenance usage [20]. (See Fig. 3) In RAMI 4.0, communication is established through the OPC Unified Architecture (OPC-UA) standard- a standard for information exchange for industrial communication [21].

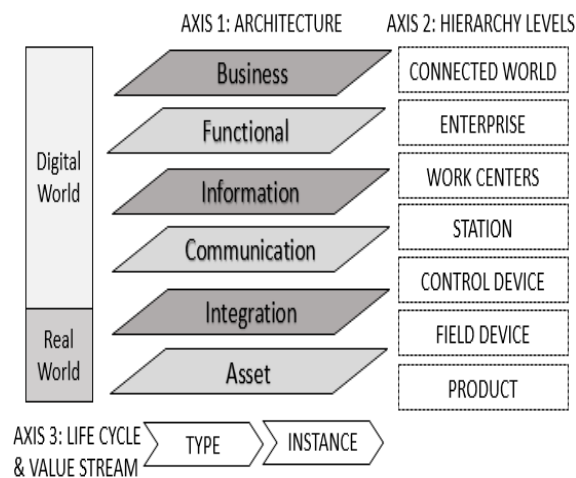


Fig. 3 RAMI 4.0 Structure

## 4. Comparative Analysis

In the following sections, we compare general characteristics and constituent elements of the IIRA functional domains and RAMI 4.0 architecture. Finally, we discuss the relationship between cloud computing and big data with IIRA and RAMI 4.0.

### 4.1. General Characteristics

The comparison is made based on the following features: country of origin, organization, purpose, basic characteristics, application scope and structure

(objectives, scope and approaches). The results of the comparison are presented in Table 1.

Table 1 Comparing General Characteristics

| <i>IIRA</i>  | <i>RAMI 4.0</i>   |
|--|---|
| <b>Country of Origin</b>   |   |
| United States  | Germany   |
| <b>Source Organization</b>   |   |
| Industrial Internet Consortium   | Plattform Industrie 4.0   |
| <b>Purpose</b>   |   |
| It defines, develops and deploys IIoT systems                              | It digitally represents an asset throughout its life cycle, up to its scrap and allows the connection between assets through the <i>Industrie 4.0</i> component |
| <b>Basic Characteristics</b>   |   |
| It is a standard based open architecture of high level of abstraction [17] | It is a 3 dimensional, interrelated and service oriented architecture   |
| Generic to apply in most types of industries<br>Promotes interoperability  | Specific to digitally represent an asset<br>Describes in detail the <i>Industrie 4.0</i> component, the Shell administrator and the cyber physical systems      |
| Based on ISO/IEC/IEEE 42010  | Based on the Smart Grid Architecture Model (SGAM)   |
| It focuses on the system lifecycle process                                 | It focuses on the product lifecycle   |
| Safety and security are characteristics of the IIoT System                 | Security is a crosscutting aspect. – Promotes design safety   |
| <b>Application Scope</b>   |   |
| Manufacturing, Energy, Healthcare, Public Domain, Transportation           | Manufacturing value chain   |
| <b>Structure</b>   |   |
| It consists of four levels called viewpoints                               | Three-dimensional, is formed by three axes that form a cubic layer model.   |
| The viewpoints are:  | The axis are:   |
| 1. Business  | 1. Architecture   |
| 2. Usage   | 2. Hierarchy levels   |
| 3. Functional  | 3. Life cycle & value stream  |
| 4. Implementation  |   |

In summary, RAMI 4.0 focuses on manufacturing considering the value chain and the product life cycle while the focus of IIRA is to build, implement and operate IIoT systems. As an example, parts and pieces manufactured in accordance with RAMI 4.0, are elements of the systems operated by IIRA.

#### 4.2. Constituent Elements

According to IIRA and RAMI 4.0 descriptions in Sections 3.1 and 3.2 respectively, the comparison of their constituent elements is presented in Table 2.

Table 2 Comparing Constituent Elements

| IIRA Viewpoints            | RAMI 4.0 Axis              |
|----------------------------|----------------------------|
| Business                   | There is no correspondence |
| Usage                      | There is no correspondence |
| Functional                 | Architecture               |
| There is no correspondence | Hierarchy levels           |
| There is no correspondence | Life Cycle & Value Stream  |
| Implementation             | There is no correspondence |

The abstraction in IIRA modeled through levels, while in RAMI 4.0 through axis. The correspondence is established between the Functional and the Architecture levels. The IIRA Functional level in merges the functions of IT and OT, and focuses on the operation of the IIoT system; while the RAMI 4.0 Architecture axis of represents the IT associated with industry 4.0

#### 4.3. IIRA Functional Viewpoint and RAMI 4.0 Architecture Axis

Based on the results explained in Section 4.2, we compare in more details, the IIRA Functional viewpoint and the RAMI 4.0 Architecture axis. As mentioned in Section 3.1, the IIRA Functional viewpoint is divided into five domains: Control, Operation, Information, Application and Business. Between them, there is flow and control of data. Namely, in the Control domain, the data of the sensors and physical elements of the real world are obtained to perform sensing, control and actuation of them.

In the Operation domain, the information of the industrial control and maintenance systems is processed to guarantee continuous operation. Among the functions of this domain are remote monitoring, configuration and update, diagnosis and preventive maintenance. In the Information domain, data from other domains is

collected, especially from the control domain, for the analysis of the entire system and decision making in real time, optimization of operations and system improvement. The Application domain applies specific use cases, rules and models. It contains the high level information for the global optimization of the system. Finally, the Business domain deals with information for the integration between existing and new systems, such as: Customer Relationship Management (CRM), Enterprise Resource Planning (ERP), and Manufacturing Execution System (MES).

The RAMI 4.0 architecture axis is described in Section 3.2 and results of the comparison with the IIRA Functional viewpoint is shown in Table 3.

Table 3 Comparing IIRA Functional Viewpoint with RAMI 4.0 Architecture Axis

| IIRA Functional Viewpoint         | RAMI 4.0 Architecture Axis |
|-----------------------------------|----------------------------|
| Physical systems                  | Asset                      |
| Control domain                    | Integration                |
| Connectivity domain               | Communication              |
| Information domain                | Information                |
| Operation and application domains | Functional                 |
| Business domain                   | Business                   |

Physical systems and the Asset level correspond to physical components of the real world, documents, software and people. The Control domain obtains data of the assets to control them immediately. The level of integration takes the digital information of the asset and relates it to the real asset. The IIRA Information Domain and the RAMI 4.0 Information Level have similar functionality. They both concentrate on the data and the technical functionality of assets, such as sensors, machines, tools, and applications. They are also responsible for analyzing data to provide intelligence to the system [17].

#### 4.4. IIRA, RAMI 4.0, Cloud Computing and Big Data

The sensors are becoming smaller, which decreases their cost and are equipped with greater computing capacity, which is why they are currently integrated into various assets [10]. In an IIoT system, thousands of assets communicate with each other, exponentially increasing the volume of data from digitized industrial processes, demanding an extraordinary computing capacity. One of the characteristics of the IIoT is to allow the storage and processing of data in the cloud, as well as the analysis and control of the OT infrastructure from the cloud. By having the data in the cloud high

availability is achieved because data can be accessed from anywhere. It also provides flexibility because access can be with different types of devices. Manufacturing environments are characterized by managing confidential information of products, formulas, processes, etc. Cloud computing allows the configuration of public, private or hybrid networks, with the hybrid network being the best option for the security of industrial information. Another characteristic of this environment is the latency time for which cloud computing allows to configure "fog computing".

In the IIRA Control domain, all data of assets is collected. In the Information domain, the data of the other domains, including data of the Control domain is collected to analyze them. (see Fig. 4)

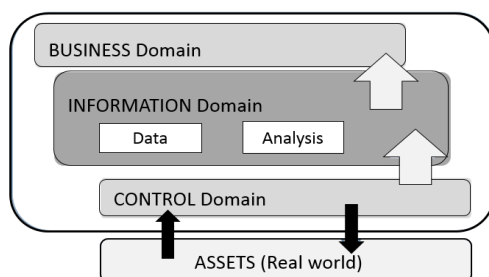


Fig. 4 IIRA Information Domain – Data Flow

The RAMI 4.0 Information level contains data of the asset's functionality in real time. At this level the data is stored and analyzed (see Fig. 5)

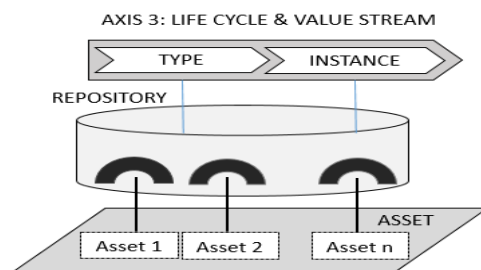


Fig. 5 RAMI 4.0 Information level – Data Flow

The enormous volume of data that is managed at these levels as well as the flow of data exchanged with the adjacent levels make the use of cloud computing and big data relevant [22]. It should be noted that "communication from cloud to cloud and from company to cloud is still under discussion within the Industry 4.0 community". Likewise, as a contingency measure, the Information domain must be outside the company, a situation that cloud computing also facilitates. Finally, the growth of the data volume, as well as its complexity, requires the use of advanced analytical approaches of big data to correlate the life cycle information of the product, which includes after sales.

Representatives of Plattform I4.0 and the IIC joined forces to identify common aspects of the two

reference architectures IIRA and RAMI 4.0 [1]. In December 2017, they published a technical report of the Industrial Internet Consortium concluding that the two architectures present more similarities than differences and that cloud computing is a complementary approach [17].

In this context, German companies such as Bosch, Siemens and Deutsche Telekom have embarked on projects to implement Industry 4.0 and also offer Industry 4.0 solution portfolios. Volkswagen, Bayer, Mercedes Benz, BMW have underway Industry 4.0 projects. IBM, SAP, Microsoft, Deutsche Telekom, Oracle, Software AG and others offer cloud integration platforms as a service. Bosch SI, IBM, SAP, Microsoft, Deutsche Telekom, Cisco, among others, offer software solutions, big data solutions and industrial big data for the collection and processing of massive data on industrial assets. Also, Adidas is implementing the approach in the Mexico factory [23]. It should be noted that Bosch presented in 2016, at the "Bosh Connected World IoT" Conference in Berlin, a project for its plant in Hamburg, Germany, to manage and optimize the production of a hydraulic valve that allows reducing electricity consumption using the two reference architectures: RAMI 4.0 and IIRA [24]. Industry 4.0 also impacts on employment, driving changes in education and the culture, towards digitalization transformation [2].

## 5. Conclusions and Future Work

Industry 4.0 digitalizes production processes through a digital representation of the real world and the interconnectivity of its actors. In this process, real-time data is generated from different sources and of different types, which produces large volumes of data. These data must be stored and analyzed in order to create value for the industry to satisfy a globalized and competitive market that demands customized products.

The research field on IT that enables Industry 4.0 is very broad and changing. Likewise, it depends on the emergence of disruptive technologies that are related to manufacturing. However, two key technological pillars for Industry 4.0 are: 1) *cloud computing* - facilitating the storage of production data in a way that supports and allows the interconnectivity of production processes with suppliers and customers; and 2) *big data* - supporting the advanced analysis of the information collected that grows in size and complexity. The use of both technologies is independent of the size of the industry and the reference architecture model chosen. This should be in accordance with the business innovation strategy and customer-orientation practices adopted by each company.

The two reference architectures - IIRA and RAMI 4.0, have a common goal: to digitize industrial operations and optimize their manufacturing processes through technology. They

are complementary. However, the level of information of the RAMI 4.0 Architecture axis has a function similar to the IIRA Functional information domain. They are characterized by two aspects: 1) the large amount of data stored, for which the adoption of cloud computing is up most relevant; and 2) the advanced industrial data analytics that must be applied based on big data.

As shown, the use of cloud computing and big data for Industry 4.0 is key and opens a range of opportunities for future research. Possible research lines are discussed below.

The development of big data and its relationship with issues of information security and cybersecurity is still very incipient and presents great challenges. An extremely relevant topic for future research is the management of information security for Industry 4.0 processes, as well as issues related to information ownership, access control, digital identity, cryptography, and encryption, among others. Similarly, the high degree of interconnection of Industry 4.0 requires standards to facilitate its implementation. For this reason, it is necessary to deepen the study of existing standards currently on cloud computing and big data to identify which should be adapted and which should be defined so to ensure interoperability and complementarity. The ISO/IEC JTC 1/SC 38 Committee on Cloud Computing and Distributed Platforms is developing standards for the use of cloud computing for data storage and communication between machines and humans. The ISO/IEC JTC 1/WG 9 Big Data committee is working on the development of standards to define the architecture that allows the efficient use of big data and evaluate the collection of unstructured data to optimize production and logistics processes. Aspects such as business continuity management systems, cybersecurity of industrial automation and control systems, safety risk assessment and system design, product development requirements, robotics, must also be standardized [25]. Likewise, communication from cloud to cloud, and from company to cloud, is currently under discussion, which offers opportunities for future research. Finally, it is necessary to have qualified professionals in these techniques. Therefore, the development of training programs to develop human capacity in topics related to cloud computing and big data for Industry 4.0 is critical.

### Competing interests

The authors have declared that no competing interests exist.

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