ECOFACT Platform Architecture Supporting Manufacturing Energy Management and Holistic Sustainability

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***Abstract*—The European Union (EU) manufacturing industry of the future needs to be led by the decarbonisation imperative and by those drivers of change leading the 4th Industrial Revolution, e.g. digital transformation, greater circularity and resource efficiency. In this work, the authors introduce a new platform based on layered architecture that integrates several assets, enabling manufacturing industries to optimize the energy performance of their production systems in line with their relevant constraints. The platform will be developed in the context of the ECOFACT project as a component of an holistic solution spanning from cloud to edge that will allow integrating energy-related information through the uptake of advanced Information and communication technologies (ICT) and digital solutions, while contributing to reduced environmental footprint and enhanced integral sustainability in manufacturing management.**

***Index Terms*—Internet of Things (IoT); industry 4.0; digitalization; energy efficiency; sustainability.**

I. Introduction

The 4th Industrial Revolution will be driven by the decarbonisation imperative as well as by digitalisation, new services, greater circularity and resource efficiency, having a high impact on the energy and production systems. To effectively contribute to the global climate target of limiting global warming below 2°C, the industry sector needs to become smarter and more efficient.

One first driver to achieve this objective is *digital transformation*, a process already in act with a wide set of services that currently support the manufacturing industry in a broad sense. These services, combined with advanced management and use of massive data, enable a multicriteria production process optimization (e.g., in terms of efficiency, uptime and quality). However, to fully exploit this huge potential, several challenges related to connectivity, interoperability and communication of intelligent devices and services need to be tackled.

Another driver is the *integrated sustainability*, indeed, the increase of energy efficiency, the uptake of Renewable Energy Sources (RESs), and the deployment of low-carbon process routes are critical paths to face the challenges derived from climate change, growing populations, pollution or resource scarcity. This requires for the manufacturing sector a paradigm shift towards 'maximum added value derived from minimum resources' [1], with improved processes that use fewer resources, actively contributing to a circular economy.

This paper presents the main component of the ECO-innovative Energy FACTory Management System based on enhanced Life-Cycle Cost Analysis (LCA) and Life-Cycle Cost Analysis (LCCA) towards resource-efficient manufacturing (ECOFACT) solution, the ECOFACT software platform, presenting its architecture and explaining its integration with the other main ECOFACT solution components.

The remainder of the paper is organized as follows: Section ii presents the State of The Art (SoTA) of the architectures for IoT platforms. Section iii introduces the methodology followed to design the architecture of the ECOFACT platform. In Section iv the architecture is presented, then Section v introduces the way in which the other components of the ECOFACT solution are integrated with the platform. In Section vi, the authors present a mapping of ECOFACT, with relevant standards. Finally, Section vii depicts the authors' conclusions.

II. State of the art

Nowadays, a unique IoT reference architecture, recognized as the standard solution in this field, has been not yet designed. Different organizations and research projects have tried to define it, but, until now, without success. This section describes some of the main available IoT reference architectures, highlighting their specific characteristics. The Internet of Things Architecture (IoT-A) EU project[1] had the main objective to develop an architectural reference model for IoT systems' interoperability [2]. The architecture has been defined in 2013 when the project has finished, but its use as reference model is currently limited. The Reference Architecture Model Industrie 4.0 (RAMI 4.0) [3] is a reference architecture specifically focused on the smart industry domain and not designed to satisfy the requirements of a generic IoT application. The standard has been originally defined in Germany, but then has been driven by a group of international companies and foundations of relevant industry sectors. RAMI 4.0 is based on a Service Oriented Architecture (SOA) that combines its Information Technology (IT) components in a layered model. The Alliance for the Internet of Things Innovation (AIOTI) High Level Architecture (HLA) [4] has been defined by the AIOTI Working Group (WG) Standardization for IoT at the end of 2020. It provides a reference architecture for IoT systems, describing a Domain Model, a Functional Model and providing deployments considerations related to relevant IoT architectural matters. This work defines a novel architecture for a platform that allows combining several cutting-edge ICT technologies, e.g. Industrial Internet of Things (IIoT), Machine Learning (ML), Artificial Intelligence (AI), digital twin as enablers for data collection & processing as well as advanced decision-making. Such architecture is compliant with the main standards presented in this section, i.e., RAMI 4.0 and AIOTI HLA. The compliance of the architecture with the RAMI 4.0 standard will be presented in Section vi. After the analysis of the SoTA, in the next section, the authors will present the methodology followed to design the ECOFACT architecture.

III. Methodology

The current standard for architecture design is International Organization for Standardization (ISO)/International Electrotechnical Commission (IEC)/Institute of Electrical and Electronics Engineers (IEEE) 42010:2011 "Systems and software engineering - Architecture description" [5]. It defines a complete methodology for the architectural description of software-intensive systems, including a workflow, with the following steps: (i) identify the stakeholders for the architecture and the system to be studied; (ii) identify the concerns related to the architecture of the stakeholders and select a set of architecture viewpoints, which can address the stakeholder concerns; (iii) create architecture views with the architectural models and analyse their consistency; (iv) record rationales for architectural choices taken. To design the ECOFACT architecture, the authors have selected four viewpoints, among the seven defined by [6] on the basis of the 42010:2011 standard. These viewpoints constitute the minimal set needed to completely define the needs addressed by the architecture, how they are addressed and how, finally, the architecture will be deployed in the actual environment. Specifically, the viewpoints are: (i) *Context viewpoint*: describes interactions, relationships and dependencies between the system-of-interest and its environment. (ii) *Functional viewpoint*: it is the main view, which describes the system's functional elements, their responsibilities, interfaces, and primary interactions. (iii) *Information viewpoint*: describes how the system stores, manages and distribute the data. (iv) *Deployment viewpoint*: describes the environment into which the system will be deployed, including capturing the dependencies the system has on its runtime environment. Such viewpoints will be presented in the following Section.

IV. Architecture Views

A. Context View

As part of the architecture design process, the context viewpoint tries to describe the interactions, relationships and dependencies between the solution and its environment, which includes all the external actors able to interact with the system, such as users, entities, or other external systems.

The ECOFACT platform's context view is represented by three main macro-components denominated Data Broker Layer, Apps & Services Layer and Monitoring & Configuration Framework.

The *Data Broker Layer* oversees the interoperability mechanisms to collect, homogenize, through a Unified Data model (UDM) and offer the data collected from the field level to the Apps & Services layer. To this aim, the Data Broker Layer is composed by components able to implement a communication system for the mutual interaction of ICT elements to aggregate data and push it to the end data consumers. Within this interoperability framework, the Data Broker offers several capabilities, e.g., the publication and subscription to streams/topics of records, their storage and their real-time processing. It also supports the creation of real-time steaming data pipelines for a reliable data exchange among subsystems and applications in complex information systems.

The *Apps & Services Layer* is composed by a tools-set intended to proactively empower industries through a set of advanced data-driven applications and services, providing information and enhancing holistic decision support mechanisms for relevant stakeholders. Among others, this layer hosts the AI-enabled tools for Life-Cycle Assessment (LCA) and Life-Cycle Cost Analysis (LCCA) calculation and the Energy and Resource Management System (ERMS), integrated into the ECOFACT Platform and with other components through the Data Broker. In addition, a federated marketplace is also offered in this layer, allowing the deployment and distribution

[1] https://cordis.europa.eu/project/id/257521/it

of the AI-based applications and services developed. In the top of the stack, and close to the end-user, this layer provides the proper interfaces to the stakeholders to use the services offered by the platform following a multi-tenant approach.

Finally, the *Monitoring & Configuration framework* provides to the platform maintainers the enablers to deploy, fine-tune, configure and monitor at runtime the platform and its single components.

The context diagram is presented in Figure 1. The actors of the platform are mainly interacting with the Apps & Services Layer, which provides the dashboards that expose the platform services and functionalities, only the Maintenance Manager, in charge of deploying and maintaining the platform, interacts directly with the Monitoring & Configuration framework to configure and monitor at runtime the different components of the platform.

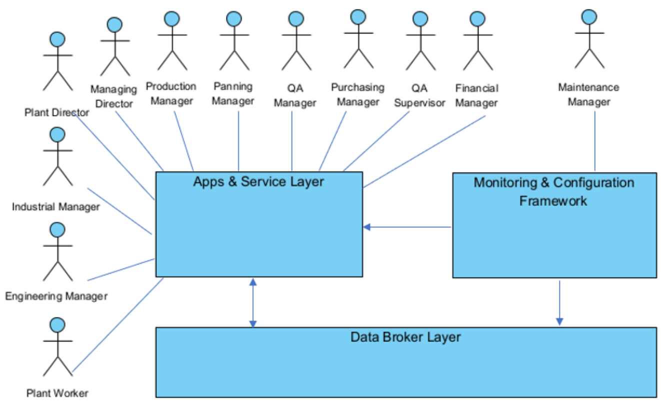

Fig. 1. Context view.

B. Functional View

Figure 2 shows the ECOFACT platform architecture, its specification follows a component-based architectural approach, where the system functions are provided by a set of well-defined, self-contained, modules named "components". Components talk to each other through well-defined interfaces, which make them decoupled from each other. Following this approach, the architecture will guarantee maximum flexibility and extensibility, since the overall solution is not bound by certain component implementations. Instead, the implementation of the different components can be replaced with different ones if they provide the same interface. In the proposed architecture, this will allow change type of Data Repository without the need to change the whole ECOFACT platform, if the same interface and format of data are used. In this way the architecture supports a plug-in oriented approach. The main components of the platform are: (i) the *Data Broker*, in charge to provide a set of Application Programming Interface (API) to the other components of the platform, to the Local Data Acquisition System (LDAS) deployed in the pilots and to the External Sources and Services (ESS), to allow them to communicate with each other. This component leverages the asynchronous publish / subscribe paradigm and its main functionalities will be: to support standard data models to promote interoperability; to support the access to historical energy data for demand forecasting as well as information about sensors (both thermic and electric) located in each pilot site, stored within the Common Knowledge and Data Repository (CKDR); to support continuous data streams and exchange of data among platform components. It defines also the UDM, used to harmonize the data format between the ECOFACT components (ii) the *Device Management* has the main role to interconnect the platform with the device management capabilities implemented by the LDAS (see Section v and the heterogeneous integrated platforms. The main functionality supported will be the alignment of the data repositories in the platform and in the LDAS, supporting, e.g., the update of devices' list when new devices are added, but also updating the list when will be notified from the field that a device is no more available. (iii) the *Data Management Functions*, a set of functions to filter, normalize and, in general, improve the quality of the data collected to maximize the information capacity and validate its quality, to enhance the efficiency of comprehensive machine learning algorithms. Such functionalities will be developed as software modules that will automatically pre-process the data exchanged through the Data Broker. (iv) the *CKDR* that will provide both the database for storing the information about sensors (both thermic and electric) located in each pilot site as well as a set of API to allow the other software components to retrieve it, using different research parameters. (v) the *Platform Manager* to be used by the platform managers to deploy, configure and monitor the components of the ECOFACT platform. Based on opensource technologies, e.g., Kubernetes, it will provide through a dedicated dashboard the services needed to control the platform. The main functionalities to be supported by this component are the deployment of the ECOFACT platform components; the managing / configuring of the interconnection among ECOFACT platform components; the monitoring of the status of the platform components and possibility to notify non-availabilities of specific components in real time. (vi) the *Holistic Decision Support System (DSS) Engine*, that will collect data coming from different sources and combine it, with the user knowledge, to provide support to the ECOFACT users in the decision-making process. The DSS will be designed to suggest actions and provide indicators, which will help understanding the expected impact of such actions on the energy efficiency of the monitored processes, with a view of the impact along the supply chain. Furthermore, the system will provide means to formalize the knowledge, using standard format. The system will be able to store, using this standard both the expert knowledge and the past decisions taken by the users. Indeed, thanks to the closed loop system developed, the knowledge base will be updated also based on the decision taken in the past by the users, i.e., if a relevant number of users take a decision that doesn't respect a specific suggestion made by the DSS, the system will be able to recognize that probably that specific suggestion is not correct and the knowledge base should be changed accordingly. (vii) the *User Interfaces (UIs)/Dashboards* will provide a unique interface that will allow also to access dashboards offered at different levels of the overall ECOFACT solutions. This will be based on a business-centric and data-driven view: the first one will enable accessing to production data and focus on a series of business cases; the latter will enable to go one level down and gain insights on how these suggestions and/or alarms are derived. (viii) the *Cybersecurity Framework* will be in charge to ensure compliance with relevant cybersecurity and privacy mechanisms: the platform design will be used for compatibility, interoperability and security of data storage and exchange from industrial environments. In addition, the platform will integrate tools for managing identities, permissions and information sharing. Thus, ECOFACT will provide end-to-end security across all layers of the platform integrating in a seamless manner accountability of univocal authentication of devices and users; encryption of data while exchanged among several platform components; security to reduce vulnerabilities and risks from the data generation; secured software components; applying privacy-related policies for data collection and sharing, i.e., General Data Protection Regulation (GDPR) compliant; enabling intelligible audits to understand and detect undesired situations from a security point of view. (ix) the *Federated AI model marketplace* that will provide a catalogue of AI models contributed by the community that can be securely shared, maximizing the potential and the impact of the ECOFACT innovative solutions. To allow this, the solution will be based on already existing open-source software, e.g., ACUMOS-AI, allowing to leverage and contribute to an existing marketplace. This software will allow to onboard AI models and toolkits, providing interfaces to upload the models in a toolkit and language agnostic way. Furthermore, it will provide API to allow automatically interconnect and chain models and toolkits as microservices as well as means to automatically deploy and execute the AI modules and applications as Docker images, to run in the cloud or private environments. Finally, it will be possible to publish the onboarded models in a marketplace to share them with other people allowing them to download, test and rate the provided solutions. (x) the *ESS* that is constituted by a set of adapters used to integrate open data sources and services that will be leveraged by the other platform components to obtain information on context related information, e.g., supply chain's energy related data to be integrated into the dynamic LCA/LCCA models or weather conditions to be used in the forecast algorithms. Since these data sources will be heterogeneous, the platform will provide a set of adapters able to integrate different sources, translating their data in the common data model used by ECOFACT.

C. Information View

The ECOFACT platform includes a component that oversee the overall platform configuration and monitoring, i.e., the Platform Manager. The platform's maintainers will use it to send the configuration to the specific components Figure 3*(1)*. On the other side, the components will send information to the Platform Manager on their status, allowing to react promptly if one component doesn't work *(2)*. The ECOFACT platform is built on top of the distributed LDASs (see Section v. The first point of contact of the LDAS with the platform is the Data Broker, which is responsible to aggregate data both real-time and historical and push them to data consumers *(3)*. The Data Broker can also incorporate data coming from ESS *(4)*. The data is first pushed into Data Management Functions, for appropriate preparation like filtering, normalisation etc. before being consumed *(5)*, then the data is pushed to the CKDR for storage *(6)* or directly to the subscribed data consumers, in real-time *(6)*. The data consumers of both real-time and historical data are the components of the ECOFACT Apps&Services layer, the "brain" of the ECOFACT platform. It comprises several cognitive components that can be data consumers and/or stream processors transforming the input data to output data pushed back to the Data Broker *(8)* to be stored in the CKDR *(9)*, to be shown to the stakeholders - in the UIs / Dashboards *(10)* or to be consumed by other components *(10)*.

D. Deployment View

As shown in Figure 4, the ECOFACT platform will be a cloud solution, with three main access points: the multi-modal web-based UI / dashboard, to allow users to enjoy the services provided by the platform, the data broker to collect data from the LDAS deployed in the field and the platform manager to configure and monitor the platform components. For the holistic DSS components, the docker technology will be used, allowing a developer to package up an application with all the dependencies it needs into containers to isolate it from the host environment. The Federated AI Marketplace will be deployed as a docker based solution running in a Kubernetes cluster[2]. This will allow to easily deploy and share the AI components developed in ECOFACT. Also the components of the Data Broker Layer will be deployed leveraging a cloud native solution based on docker, so they will run as docker container and they will be accessible also by remote through the provided API. Finally, the Platform Manager will be deployed in a server and connected to all the components that it can configure and monitor.

After have presented the ECOFACT platform, the next section will present the integration of the platform with the other main components of the overall ECOFACT solution.

V. ECOFACT SOLUTION

The ECOFACT solution is a complete system to enable manufacturing industries to optimize the energy performance of their production systems. Beside the ECOFACT platform presented in the previous section, it includes also the LDAS used to integrate the physical resources from the field as well as the ERMS and the Dynamic LCA/LCCA, which are intelligent modules plugged in the overall platform to do calculation related to energy efficiency and LCA/LCCA, respectively. The next subsections briefly explain the integration of these macro-components with the ECOFACT platform.

[2]https://kubernetes.io

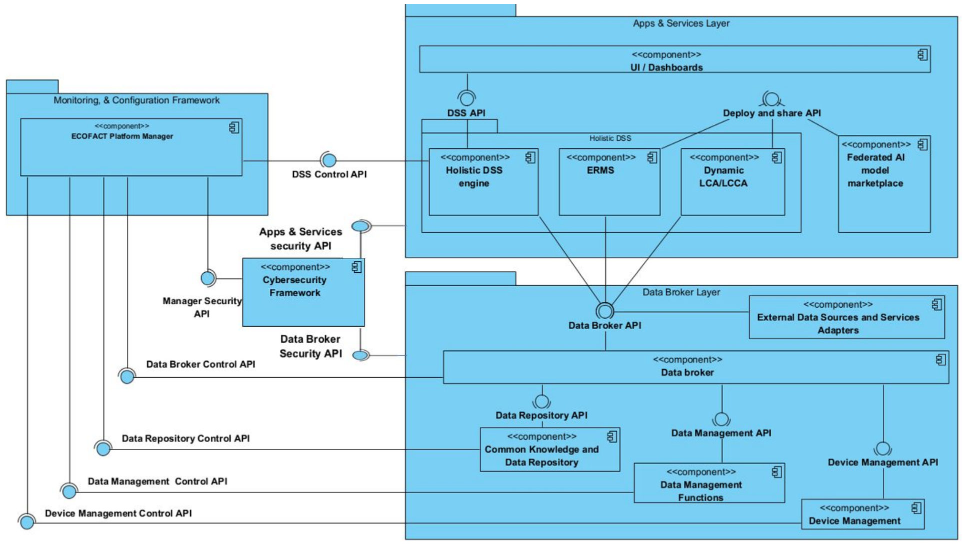

Fig. 2. Functional view.

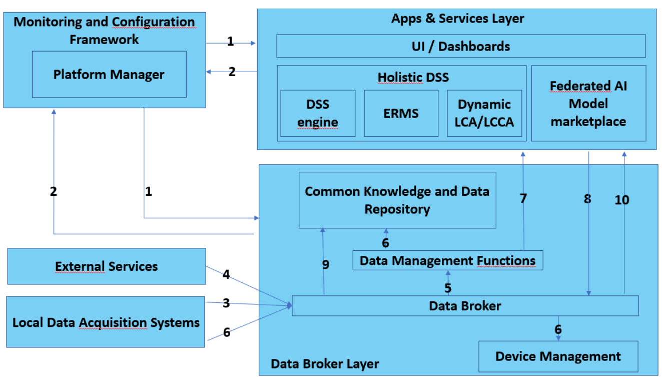

Fig. 3. Information view.

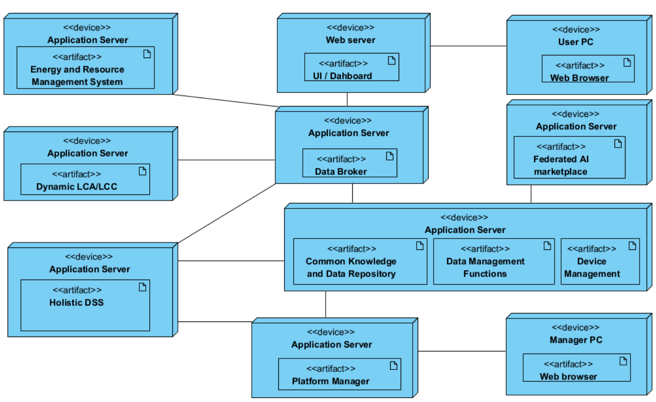

Fig. 4. Deployment view.

A. Integration with Local Data Acquisition System

The LDAS acts as edge layer for the ECOFACT platform and has the purpose to collect energy consumption data and forward it to the platform. However, the data collection for each company differs a lot, due to various local monitoring architectures as well as monitoring hardware and software from different vendors. Although different data collection technologies are deployed, the data model and the API to the ECOFACT platform must be consistent. In this sense the architecture for LDAS is designed to match the requirements of local vendors and on the other hand provide a uniform API to the ECOFACT platform. Merging these two parts forms the LDAS architecture.

The LDAS is deployed locally at the manufacturing industry that will be connected to the ECOFACT platform. The first part of the LDAS is adapted to the specific requirements and available data collection structures of the company. This part is based on existing solutions from the platform providing vendors. In the ECOFACT project these are the EcoStruxure™ Power Monitoring Expert[3] from Schneider Electric, the Artemis platform[4] from Wings ICT Solutions and the Smarkia 50001 platform[5] from Smarkia. All three platforms are connected to local data acquisition systems like Programmable Logic Controller (PLC), Supervisory Control And Data Acquisition (SCADA) or Manufacturing Execution System (MES) systems. The gathered data is exposed to the second part of the LDAS, the uniform part of the edge layer. This additional module is necessary to normalize the different protocols and data models of the existing platforms.

B. Integration with the Energy and Resource Management System

The ERMS will include the ECOFACT Digital Twin platform and a set of algorithms for production planning, energy flexibility and energy disaggregation. It will include a data-interoperability layer to enable interoperability between different information systems of the ECOFACT solution. The

[3]https://www.se.com/it/it/work/products/product-launch/power-monitoring-expert/

[4]https://www.wings-ict-solutions.eu/solutions/utilities

[5]https://www.smarkia.com/en/solutions/smarkia50001/benefits

Interoperability Layer will integrate tools and services providing a set of APIs based on the Representational State Transfer (REST) architecture. JavaScript Object Annotation (JSON) and eXtensible Markup Language (XML) formats will be used for the exchange of information.

C. Integration with the Dynamic LCA/LCCA

The Dynamic LCA/LCCA software module will include the following functionalities: (i) dynamic LCA/LCCA models implemented in the SimaPro[6] as a service platform, (ii) a supply chain collaboration service to share data with suppliers, and (iii) algorithms supporting prioritization of life-cycle targets based on an Analytic Hierarchy Process (AHP). The LCA/LCCA models will use the SimaPro calculation engine to calculate environmental and economic impacts stemming from the ECOFACT pilot sites' production. The models will take input data from the data broker and the impact results will be made available to other ECOFACT components. The supply chain collaboration service will make supplier data available to the ECOFACT platform. Through the ECOFACT data broker, this service will ensure that all the modules have the key information they need from the demos. The AHP algorithms will use the impact results from the LCA/LCCA models to derive insights about improvement opportunities and their impact reduction potential. The ECOFACT platform and SimaPro will interact through interconnection between the the SimaPro REST API, provided over HyperText Transfer Protocol Secure (HTTPS) protocol and the API provided by the Data Broker.

VI. Standards Compliance

As mentioned before, the ECOFACT solution has been designed to be compliant with the main standard reference architectures.This section explains the mapping of ECOFACT components on RAMI 4.0 (see Figure 5). Specifically, on the *Business Layer* there are the UIs/Dashboard, the Holistic DSS, the ERMS, the Dynamic LCA/LCCA module and the Federated AI Marketplace. On the *Functional Layer* there are the Holistic DSS, the ERMS, the Dynamic LCA/LCCA module and the Federated AI marketplace. On the *Information Layer* there are the CKDR, the Data Management Functions and the Device Management. On the *Communication Layer* there are the Data Broker and the Cybersecurity Framework. On the *Integration Layer* there are the LDAS and the ESS. Finally, on the *Asset Layer* there are the physical devices integrated. Beside the mapping on the layer, another mapping shown is the one on the hierarchy levels of RAMI 4.0 [7], [8], in this case all the components of the ECOFACT platform, the ERMS and the Dynamic LCA/LCCA are on the *Connected World* level, the LDAS is on the *Enterprise* and *Work Centers*. Finally, the devices integrated on the pilot sites are on the *Station*, *Control Device*, *Field Device* and *Product* levels.

[6]https://simapro.com/

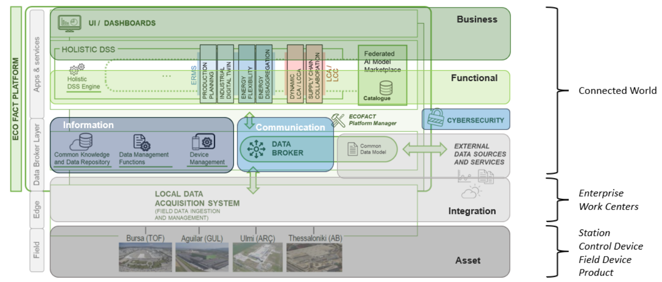

Fig. 5. Mapping of the ECOFACT solution on the RAMI 4.0 reference architecture.

VII. Conclusion and Future Works

This paper has presented the architecture designed for the ECOFACT platform, the main component of the ECOFACT solution, a complete system to enable manufacturing industries to optimize the energy performance of their production systems. The paper has explained the design choices, the methodology followed and then described the architecture using different viewpoints. Finally, the paper has explained how the platform integrates the other main components of the ECOFACT solution and shown the compliance of the system with one of the main IoT reference architectures. The components of the architecture are currently under development and the definition of the UDM to be used is ongoing. During the implementation of the components, the architecture will be continuously refactored to follow an agile approach satisfying new requirements, not clear at design time.

VIII. ACK

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