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A framework for asset centered servitization based on micro-services

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Abstract. This paper focuses on the proposal of a framework for a servitization model applied on an asset centered environment – including production machines as the physical assets – and populated by micro-services as the means to deliver the asset-related services. The asset centered servitization is, for many production machines manufacturers, a core value proposition. As a matter of fact, servitization represents a business-model change, with companies moving from selling goods to selling an integrated combination of goods and services. Competitive advantage is an outcome of this shift. This research proposes an evolution from the traditional, monolithic approach of servitization, often materialized in the concept of "platform/catalogue of services" to choose from, towards a modern view of "environment of micro-services" in which the physical assets are immersed. In the proposed framework, micro-services are summoned and function depending on the operating conditions and the actual usage, so to achieve a flexible and dynamic environment by design.

Keywords: Micro-services, data-driven Product Service Systems, Physical Assets

1 Introduction

From the moment it was first spotted in academic literature [4], the "Servitization of Business" was defined as the tendency of adding value to products through service. This concept sparked radical business transformations by expanding the offer to customers and by creating new revenue streams. One of the core aspects is how to deliver the servitization while maintaining sustainable performance levels for the industry; hence, being scalable, robust, effective, and providing high and consistent performance, is fundamental for the success of the business transformations. However, many are the challenges (data not available, restrictions in accessing the internet, etc) to build an effective and efficient service delivery architecture, in case of technical services such as maintenance which requires a range of activities, from the collection of data, through the application of advanced data analytics, to the engagement of all the decision-makers [2]. This is especially true when the service is extended from operational to tactical and strategic decisions, which compel the discipline of Asset Management (AM), Furthermore, it has been pointed out how the adoption of AM grants a better inclusion of stakeholders affected by the service of the asset(s). It is at this juncture that the concept of micro-services falls into place, as a way to evolve from monolithic approaches in offering services to a flexible solution more adaptable to customer needs and requirements.

The notion of delivering services with micro adaptive containment - that is: micro-services - was originally defined and developed for ICT applications [5], with the main idea to split software and applications into smaller "functions" working together to deliver the same, original intended result. These functions could be shared between multiple applications, thus increasing the effectiveness of each micro-service and also favoring a modular approach for services offering. Due to the inherited flexible nature of micro-services, computer scientists developed "Kubernetes" as an open-source container-orchestration system for automating computer application deployment, scaling, and management of micro-services. It was thanks to Kubernetes that micro-services were perceived as a real "way to go" in programming complex applications.

Building on the potential provided by micro-services, this paper postulates that AM needs a framework to configure and manage services in order to benefit from micro-services key features and advantages for asset operations management and governance. Furthermore, considering that the theory of data-driven PSS is at an early stage [6], the proposed framework aims to bring a contribution to such theory as a concrete concept linking information and data flows due to the digital transformation, to a flexible and dynamic capability to configure and manage services delivered to support the AM.

2 Literature Review

The literature review was carried out to understand the current state at the interception of the three areas this research revolves on, which are servitization, AM and micro-services. The review, based on a combination of open web search, Google Scholar and Scopus, is composed by three phases: (1) the topic and the scope perimeter definition; (2) the documents selection and (3) the value extraction.

Phase 1 consisted of the definition of the topics and keywords to properly direct the literature search (see Table 1). The keywords definition is influenced by business needs and strategy of the case company where this research is placed; thus, the scope definition should be considered coherent with the company business value proposition.

Macro-topic	*Main keyword*	*Alternative keywords*
Servitization	Servitization	Service, Product-Service System
Asset	Asset Operations	Asset Management, Fleet Management
Micro-Services	Micro-services	Containers, Kubernetes, Componentization via Services

Table 1: keywords selected

Phase 2 consisted in the selection process, built on the document metadata, tags, title and abstracts, and the following inclusion criteria: (1) English-written documents only; (2) Peer-reviewed papers and conference papers, also extending the review to "grey" literature; (3) Publication year as the research was limited to documents published starting from 2005 (included) onwards (year of introduction of the modern definition of micro-services).

Phase 3 consisted of a full-body critical analysis of each relevant paper selected in the previous phase, to extract the key take-aways from which this work extends from.

From the literature findings it is possible to see that the trends about servitization and micro-services (two main keywords connected with this research) show a growing interest (Fig. 1). These signals are coherent between themselves (similar increase) even if – by analysing the sources – the trend of servitization relates a community interested in business topics, whereas the trend of micro-services is mostly confined to the technological (IT-related) topics.

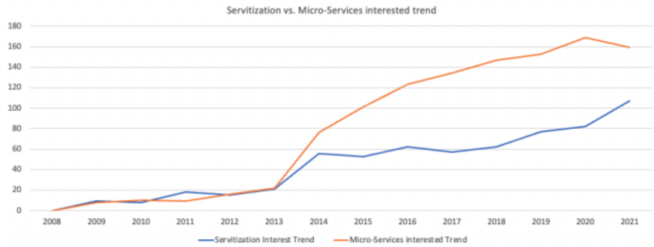

Fig. 1 - "Servitization" and "Micro-Service" keyword trend

Focusing on the trends of asset operations (the third main keyword), this is also growing: the major share of the upsurge in interest is fueled by a managerial attention of asset operations (Fig. 2).

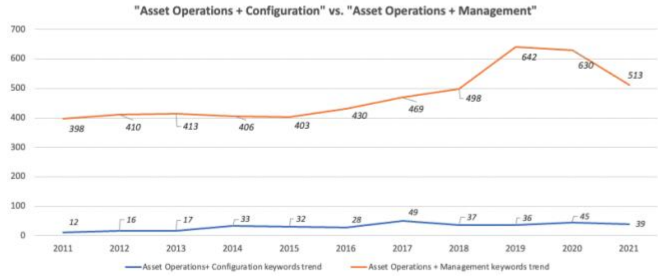

Fig. 2 - "Asset Operations" keyword trend with 2 research attributes [Configuration and Management]

The following Table 2 provides a summary of the distribution of the literature findings, with information about the percentage relevance to the research scope, the subject area (Computer Science vs. Industrial Engineering), the language (English) and the exclusion of conference papers.

Keywords	*No. Of Results Total papers found on Platform*	*Relevance (ratio: interesting papers vs total papers)*	*No. Of papers studied and in scope of analysis*	*Subject Area*
"Servitization"	745	8%	58	Engineering + Computer Science
"Asset Operations"	2114	7%	148	Engineering
"Computing Environment"	578	2%	11	Computer Science
"Micro-Services"	143	7%	10	Engineering + Computer Science
"Asset Operations" + "Configuration"	219	4%	8	Mostly Engineering
"Asset Operations" + "Management"	1431	11%	158	Mostly Engineering
"Asset Operations" + "Micro-Services"	89	10%	8	Engineering + Computer Science

Table 2: distribution of literature findings

With a specific insight on the servitization-related findings, customization, by adapting to the needs of each customer, is fundamental to provide services responsive to the needs. The proposed framework then considers a servitization with high level of customization in asset operations, with the micro-services as technological enablers to grant the realization of a cost-effective data-driven PSS (Product Service System).

3 The Framework

3.1 Overview of the framework

The proposed framework is illustrated as three connected blocks which function in synergy as Fig. 3 shows.

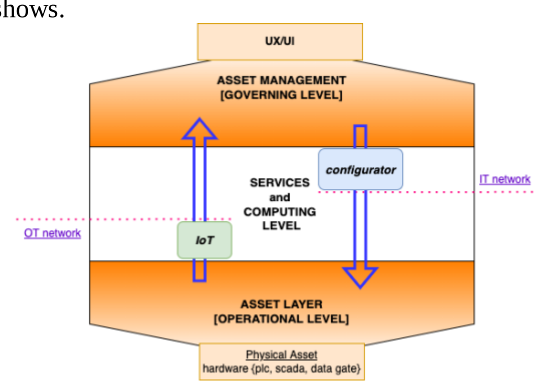

Fig. 3 - high level schema of the framework

The schema connects the UX/UI (User Experience/User Interface) block with the physical asset so to consider a flow starting from the user and ending with the production machine, i.e. the physical asset. The generic term user, can be embodied by different figures in a company: a company manager, a workshop coordinator, a production planner, etc. In general, the stance taken is of a manager with a significant responsibility and the ability to configure production machines so that they achieve their productions goals. The production asset/machine itself, is not intended only as a physical artifact; it also includes the automation and digitization components, local to the machine, such as PLCs (Programmable Logic Controllers), SCADA (Supervisory Control And Data Acquisition), data gates and brokers.

Three levels then connect the user and the physical asset. Each of these three levels performs specific transformations, by enriching and providing new inputs to the data so that the operations management and governance system is flexible and dynamic, thus adapting to the various conditions that can arise from business and operational needs.

The Asset Management level is the 1st level where – starting from business needs – the strategic decisions take place and governance is established. Here, the physical assets are governed with a specific strategy aligned with company values. This AM level concretizes in user profiles, thus translating the user needs in lieu of the original specification and features defined and planned.

The Services and Computing Level (2nd level) processes the rules, the settings, the inputs provided by the 1st level, via a configurator (in a nutshell, a 'mapping service' between existing micro-services and business needs) which seamlessly builds and recalls the necessary micro-services into newly assembled service(s). Besides, this level runs the information management from the production floor: via the IoT devices, the level processes the information coming from the physical asset itself back up the 1st level: this is the basis to create a virtuous loop for keeping the information updated.

The Asset Level is the 3rd level where the machines / production assets operate. This is the arrival point for configurations, strategic inputs, planning and deliverables coming from the above levels. It's also the most *raw*-data rich as the IoT devices and the sensors collect a variety of data related to any event happening on the production floor. Raw data will be sent back to the above levels to become information to finally leverage on asset intelligence.

The flow of information and data is one of the most important exchanges that occur across the different levels. The types of transformations through which these flows of information and data pass are different. The bottom-up flow matures raw-data into information and then into asset intelligence via (mostly) data-driven analysis, experts' interpretation and machine learning deep dives. The top-down flow starts with business needs and value propositions that are transformed into governing principles (how to conduct properly the physical assets) and output requirements (what to expect from the assets utilization). This block of information finally becomes a delivery of services such as predictive maintenance, state machine analysis, performance self-assessment and correction, etc. Overall, the two flows contribute to the creation of a PSS, which is of a data-driven type, through the adoption of micro-services to guarantee customization of the service delivery.

3.2 The role of micro-services and of the configurator of services

Micro-services are at the heart of the conversion of AM guidelines into asset operations, and the configurator – a tool that allows users to customize the components and features of a product/service so that the final configured product/service meets their expectations as much as possible – is a key function to this end.

The popularity of configurators for engineering products is increasing as the number of products is also increasing and different components/sub-products can be assembled to create customized products. Likewise, a configurator of services is also perceived as an interesting method to govern service and product-service systems. Typically, to develop a configurator of services is required a two-stage approach: (1) developing/activating the enabling technology [3] and (2) decoding business goals into the technological design [1]. Micro-services are considered as the chosen technology in this research, and a configurator of (macro) services (i.e., those delivered to the customers) is a relevant function to adjust the delivered services to the customer.

The micro-services – micro adaptive containment – enable to think on the possibility to move from the traditional, monolithic approach of servitization, which is often materialized in the concept of "platform/catalogue of services" to choose from, towards a modern view of "environment of micro-services" in which physical assets are immersed and (micro-) services activated upon requests. In this view, micro-services are summoned, and function based on the conditions and the actual usage, creating a flexible and dynamic environment by design.

To fully enable the configurator of services, the 2nd level of the framework requires that the business goals are decoded into the technological medium: micro-services need to represent atomic, micro-needs that implement the high-level business goals. This 2nd level demands the development of a catalogue of services, in which the intended services to be provided to answer the business needs of the market are built through correctly structured micro-services. These micro-services altogether – as assembly of micro-services – then determine the (macro) services associated to the physical asset and delivered to support asset-related decisions.

Depending on the complexity and the correlation among the services, the creation of the catalogue requires to split each of the services to be delivered into small functions so that their sum, as adaptive integration, returns the intended result(s) of the originating service as required. As a result, a complex web of micro-services is expected, and the catalogue itself can be understood more as a honeycomb structure, rather than a hierarchical tree structure.

3.3 Exemplar of micro-services architecture for Prognostics and Health Management within Asset Management

Even though services may be of multiple nature, predictive maintenance is one of the current hot services required by customers. For this reason, a first schema on how to structure micro-services so to provide prognostic capabilities is realized, grounded on the ISO 13334-1. This standard, also called OSA-CBM (Open Standard Architecture – Condition Based Maintenance) is useful as it is technology independent and could hence be established through monolithic as well as micro-services architecture. Fig. 4 shows an abstract case that considers the micro-services designed to realize the catalogue of predictive maintenance services to be delivered on the physical asset, classified in: Data Treatment micro-services, Anomaly Detection micro-services, Diagnosis/Prognosis micro-services, and Decision-making micro-services.

When the micro-services are implemented and the business goals (like 'risk minimization' in the specific case of predictive maintenance) decoded onto the catalogue, the configurator works as the engine which pairs a business need (or multiple business needs) with interconnected micro-services taken from the catalogue designed by the provider. Figure 4 offers insight on the way the configurator selects the micro-services from the catalogue to provide human support in a predictive maintenance strategy. All the micro-services are assembled together in order to finally achieve the intended/demanded (macro) services to be provided, as it is a notification about the Remaining Useful Life of a component and an Advisory generation on the maintenance action to be executed.

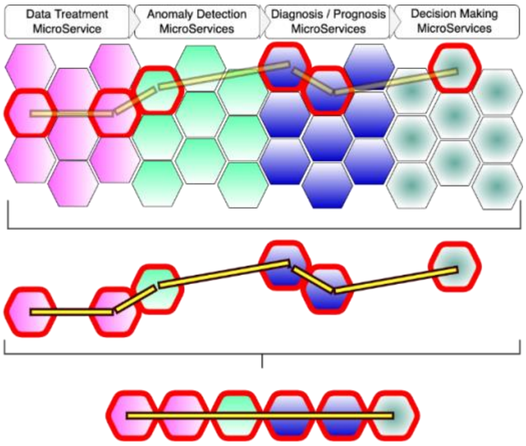

Fig. 4 – From the catalogue of micro-services to the configuration of (macro) services

On the one hand, the customer/user sees the offered (macro) services as a result of customization; on the other hand, the provider manages multiple, interconnected, enabling micro-services, to finally achieve efficiency by design to deliver the customized services. In particular, in the definition of the micro-services as small functions, it is possible to find similarities among the functions themselves and thus utilize a single one for multiple purposes. For example, an anomaly detection service can be described as the interaction of 4 micro-services [A-B-C-D] while a diagnosis service by [A-B-E-F] which shares A and B as micro-services because A executes certain data cleaning tasks and B performs a regression analysis. The services are made unique by the [C-D] and [E-F] not-shared micro-services, which then specifically lead to deliver the customized service, e.g. an alerting procedure for the anomaly detection or a failure mode isolation algorithm for the diagnosis, both of them built on the common ground brough by the coupling [A-B].

4 Conclusions

This paper presented a first concept of a framework that connects the capabilities due to a key enabling technology leading to micro-services, with the business interest of servitization and, in particular, the development of a data-driven PSS on physical assets. The concept considered the benefit by design achieved with the adoption of micro-services, while revealing the need for a proper management of the complexity of micro-services to finally obtain an efficient method for delivering customized services according to their intended use for the customer/user and operational features of the physical asset. The framework has been realized looking at AM and, particularly, to the Prognostics and Health Management, as a set of exemplar services that are highly requirements by industrial customers in the current contexts.

In future works, we expect to develop the concept further, while being driven by the business requirements derived from the value proposition of the case company and to analyze the limits of the framework, such as the need of data and their availability in the network (internal and external). The specific interest will be devoted to demonstrating that the micro-services features help achieve an efficient delivery of customized services for physical asset management.

Different abilities should be under scrutiny to evaluate the benefits of the proposed framework. Amongst them: i) the ability to re-use micro-services in multiple industrial contexts, to enable maintainability and resilience over the asset lifecycle; ii) the ability to meet remotization requirements due to specific operational conditions where the physical asset is not connected to the network and the micro-services can operate on-edge; iii) the data share-ability, considering the possibility to have different policies of access to data produced by the physical assets in their standard operations environment.

Overall, the provider is expected to not only achieve an efficient way to customize services, but also an effective capability to make a continuous improvement from the application of the same micro-services in different contexts, which grants its result(s) in different scenarios and eventually a learning experience from data in different industries.

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