Cyber-Physical Microservices
An IoT-based Framework for Manufacturing Systems

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Abstract—Recent advances in ICT enable the evolution of the manufacturing industry to meet the new requirements of the society. Cyber-physical systems, Internet-of-Things (IoT), and Cloud computing, play a key role in the fourth industrial revolution known as Industry 4.0. The microservice architecture has evolved as an alternative to SOA and promises to address many of the challenges in software development. In this paper, we adopt the concept of microservice and describe a framework for manufacturing systems that has the cyber-physical microservice as the key construct. The manufacturing plant processes are defined as orchestrations of primitive cyber-physical microservices performed by the physical plant layer. Model-driven engineering is utilized to semi-automate the development process for the industrial engineer, who is not familiar with microservices; IoT technologies are used for their integration. A case study demonstrates the feasibility of the proposed approach.

Keywords—cyber-physical systems; microservices; IoT; service discovery; service composition; UML4IoT; semantic web;

I. INTRODUCTION
The fourth Industrial revolution, referred as Industry 4.0, has a tremendous impact on the society and the global economy. IoT technologies along with Cloud computing, data analytics and cyber-physical systems play a key role in this evolution [10][16]. Manufacturing systems are greatly influenced by this revolution. It is expected that very soon the IoT-based manufacturing environment will be a reality, since the competitive nature of today’s industry forces manufacturing to move toward implementing high-tech methodologies [14]. The main objective of digitalization of production environments is to achieve a new automation paradigm, more flexible, responsive to changes and safe [2]. Service-oriented computing has attracted the interest of research and practitioners from the manufacturing domain a long time ago [4]. However, the adoption of research results in practice is not the expected one. The manufacturing industry is conservative and is expecting for a technology to reach an acceptable level of maturity before its adoption. During that time a new paradigm based on the concept of microservice appeared in SOA and promises to change the way in which software is perceived, conceived and designed [9]. Microservices are the building block of a microservice architecture and promise to address several open issues in software development. Every microservice (MS) can be reused, orchestrated, and aggregated with others [9]. Microservices bring simplicity in components management, reduce development and maintenance costs, and support distributed deployments [7]. These characteristics make microservices a promising technology for manufacturing systems. As authors claim in [27], benefits of this technology include among others, increase in agility, developer productivity, resilience, scalability, reliability, maintainability, separation of concerns, and ease of deployment.

The potential of this new paradigm has been identified and we claim that the microservice paradigm will have a significant impact on the way future manufacturing systems will be developed. Thus, in this paper we propose the integration of IoT technologies with the microservice architecture and examine alternative scenarios for their exploitation. Based on this, a framework for the exploitation of both technologies, i.e., microservices and IoT, in the manufacturing domain, is briefly presented. However, the investment in traditional technologies, as for example IEC61131 based systems, is huge. There is a need for systems and components that have been developed based on the conventional approach to be integrated and exploited in the new environment. On the other side, the adoption of microservice and IoT technologies in the manufacturing domain will greatly affect the development and operation processes of systems in this domain. Industrial engineers are not familiar with these technologies, which when adopted make the development process too complicated for them. Furthermore, there are also other challenges that manufacturing faces, such as the need to switch from mass production to mass customization, and the strong demand for real-time response at the machine control level. Microservices and IoT technologies that will be adopted in the manufacturing domain should properly address these challenges.

Model-driven engineering (MDE) is used to address the complexity of the development process as well as to get the other benefits of this paradigm in the manufacturing domain. The physical units of the manufacturing plant (referred as plant in this paper) are transformed to intelligent (smart) entities that we call cyber-physical microservices (CPMSs). CPMSs are described using web technologies and are available for discovery and use during the development time of the manufacturing system processes, but also during its operation to have a flexible manufacturing system able to address the challenge of mass customization. Moreover, the modularity at the plant process layer, that is required to address mass customization needs, is increased by modelling manufacturing process using the microservice architecture. Composite CPMSs are defined by integrating primitive ones. IoT is utilized as glue among the constituent microservices of a plant’s composite microservice as well as at the system integration level.
Microservices are considered as resources in the manufacturing environment and the Resource Description Framework (RDF) [20] is utilized to have a machine-readable specification for the primitive but also for the composite ones that the plant offers. RDF is also used to capture the domain knowledge in terms of models and meta-models which enrich the framework.

The contribution of this paper is the description of a framework for the exploitation of the emerging microservice architecture in the domain of manufacturing systems. The framework utilizes model-driven engineering to semi automate the utilization of the microservice and IoT related technologies and handle the complexity introduced by these technologies in the development process of manufacturing systems. The effects of the utilization of these technologies on the architecture of the manufacturing systems, as well as on development process are investigated and discussed. The rest of this paper is structured as follows: Section 2 presents background information and related work. The cyber-physical microservice is defined in Section 3. An implementation approach for the cyber-physical microservice is also presented. Section 4 describes the modeling of the plant process layer using the microservice paradigm and discusses description and discovery of CPMSs as key issues in the modeling of the plant. The paper is concluded in the last section.

II. BACKGROUND AND RELATED WORK

As authors argue in [12], traditional manufacturing systems are slow in responding to market or supply chain changes and this is mainly due to the fact that they are based on the 5-layer architecture (ISA-95 model). The adoption of recent ICT into the Manufacturing domain will enable real-time response to changes in the factory, the supply chain and customers’ needs [12]. To address these requirements, as well as the challenge of integration of the three different disciplines in CPSs [18], we have adopted in this work the architecture shown in Fig. 1. This architecture is based on the adoption of concepts from the cyber-physical and IoT domains [13] and is adapted to the microservices architecture. Our architecture is different from the 5-layer architecture proposed in [14] mainly due to the different understanding of the term cyber-physical. We consider as cyber-physical the lower level of the 5-layer architecture, i.e., the Smart Connection Level, that captures the tight integration of the physical with the cyber world. The 5-layer architecture defines the third layer as Cyber Level.

Research on Cyber-physical systems plays a key role in the evolution of manufacturing systems. CPSs are expected to have a significant impact on the way manufacturing systems are developed and operate. A great number of standards attempt to define a common language and the basic concepts regarding the exploitation of CPS research in manufacturing systems. Authors in [1] present a critical evaluation of international standards with the intention to help academic scholars and industry practitioners to manage challenges that should to be addressed in the fourth revolution of manufacturing systems. In [11] authors describe a manufacturing platform that utilizes Internet of Things, cloud computing, big data analytics, cyber-physical systems, and prediction technologies and claim that its application to the production process in the semiconductor domain is promising to achieve the goal of zero defect. Authors adopt RESTful services for horizontal and vertical integration of system components.

In [12] authors describe a framework for modeling of cyber-physical manufacturing systems utilizing SOA and web technologies. The framework supports, as authors claim, automatic service discovery, identification and orchestration and utilizes web service integration based on semantics. The framework is adapted to the requirements and constraints of OPC UA (https://opcfoundation.org/about/opc-technologies/opc-ua/). Our work has many similarities with the work in [12] but, a) it introduces the concept of modularity based on cyber-physical microservices, b) uses IoT technologies for the integration of functionalities, and, c) utilizes MDE to automate the development, commissioning and operational phases, to mention the most significant differences.

Modern manufacturing systems should be able to scale and evolve over time to satisfy the changing requirements of the market adopting innovative technologies and designs. The microservice architecture style has emerged and gained a lot of popularity in the industry in recent years. In [7] authors present a prototype platform that supports multiple concurrent applications for smart buildings. The proposed platform utilizes advanced sensor network in a distributed microservices architecture. Authors claim that the use of microservices results to a platform that promises strong scalability, reliability, and ease of evolution regarding hardware resources and finally direct utilization of the immense power of external services available on the Internet. In [3], authors describe an IoT platform for smart city that utilizes the microservices architecture style.

Microservices have already attracted the interest of the research community in the domain of manufacturing systems. Authors in [2] utilize microservices for the construction of a framework to facilitate the integration of simulations into the digital factory. Authors claim that they plan to extend their framework by including other more IoT-friendly, protocols like XMPP and MQTT, to facilitate the integration with legacy or heterogeneous solutions. Our work utilizes LwM2M that is implemented over CoAP. The MQTT based implementation of LwM2M allows our approach to also utilize MQTT.

Authors in [8] utilize microservices to propose a collaborative Industry 4.0 platform that enables IoT-based real-
time monitoring, optimization and negotiation in manufacturing supply chains. They claim that microservices provide better scalability, better agility and continuous delivery and facilitate new levels of customization, security, workload changes, simplify validation and testing. As service communication they utilize HTTP or the Apache Kafka messaging service. We use in our platform the OMA LwM2M that has several advantages compared to HTTP regarding the manufacturing environment, since our platform considers also the shop floor units and their integration. Instead, in [8] a specific component, the IoT component, is proposed to support communication among IoT devices and the microservices of the proposed platform using MQTT.

An infrastructure for automated deployment of microservices for monitoring purposes is presented in [5]. The author adopts the container-based approach, instead of the hypervisor-based one, and claims that the microservice approach is a promising design paradigm that is tightly bound to the container technology. Authors in [6] utilize microservices to design and implement a dynamic orchestrator in a cloud-based computing environment. The proposed orchestration framework automates the dynamic adjustment of applications to the up and down scalability of cloud resources. This work can be transformed and adapted to our framework to address mass customization needs.

To the best of our knowledge there is no other work that a) adopts and examines the microservice paradigm in the shop floor level of manufacturing systems, and b) considers the CPMS as the key construct of manufacturing systems and IoT as a glue for the integration of CPMSs.

### III. CYBER-PHYSICAL MICROSERVICES

The proposed framework is based on our previous work [17], which utilizes Model Integrated Mechatronics (MIM) in the domain of manufacturing cyber-physical systems. In this transition from mechatronic systems to CPSs we have considered CPSS as extension of mechatronic systems. Arguments on this view can be found in [15].

#### A. Microservice-based development of manufacturing CPS

In this work we adopt the microservice paradigm and define the cyber-physical microservice as the key construct of the cyber-physical system. As shown in Fig. 2, the manufacturing cyber-physical system is defined in the cyber-physical microservice layer as a composition of well-defined CPMSs. A CPMS is composed of tightly integrated mechanics, electronics and software with the objective to realize specific functionalities that would offer to its environment. A CPMS has also, along with its software interfaces, well defined electronic and mechanical interfaces, which differentiates it from traditional microservices of the software domain. All these interfaces are defined using the SysML construct of provided and required interface [17]. AutomationML can also be used for this purpose. The identification and definition of CPMSs for a domain, e.g., assembly systems, and a specific application is a great challenge. It requires very good knowledge of the domain, so as to properly capture a) the domain knowledge into domain MSs, and b) the application knowledge into application MSs.

![Fig. 2. A microservice and IoT-compliant architecture for Cyber-Physical manufacturing systems.](image)

#### B. Primitive and Composite cyber-physical microservice

A CPMS implements its functionality by a close integration of physical and cyber artefacts. It offers a specific and narrowly defined physical functionality, such as heat and mix, enriched by cyber artifacts and is deployed on the plant platform as an independent service but within the context defined by the constraints imposed by its mechanical part. CPMSs apply on physical objects, e.g., assembly parts, and transform their state. CPMSs interact with their environment through well-defined ports (CPMSPort) that are characterized by their provided (itsProvidedIf) and required (itsRequiredIf) interfaces. We discriminate microservices into primitive and composite microservices, as shown in fig. 3, which captures part of the UML4IoT profile [13] that has been extended to support the CPMS paradigm.

![Fig. 3. Part of the UML4IoT profile that captures Cyber-physical Microservices.](image)
LwM2M IoT protocol is adopted for their interaction. The communication mechanisms adopted in various levels of the manufacturing environment, it should be transformed into a CPMS that provides a RESTful interface. We have adopted the OMA LwM2M application layer protocol, which is implemented on top of CoAP, (an MQTT based advanced message queuing protocol (amqp) (https://www.amqp.org/)) and UDP sockets are used as network communication mechanisms in the case of different nodes (2N). The table also captures the overhead introduced by the network communication mechanism in the case that both client and server microservices are deployed on the same node (1N). It should be noted that the table shows measurements using as node the RPi (1N), which introduces significant performance overhead regarding the execution of the protocol stack of the server side. Therefore, the round trip for two nodes (2N) appears to be higher than the one on the same node (1N). The corresponding measurements for lwM2M on the Intel i5 node (1N) present an avg. 1.77 ms with min. 0.52 and max. 17.7 ms.

| Lifecycle | IPC | Network Communication |
|-----------|-----|-----------------------|
| Unix socket | Pipes | LwM2m | amqp | UDP Sockets |
| avg | 0.21 | 0.29 | 8.74 | 4.9 | 2.74 | 1.33 | 0.34 | 0.5 |
| min | 0.10 | 0.08 | 3.52 | 2.01 | 0.81 | 0.61 | 0.2 | 0.28 |
| max | 23.23 | 9.34 | 138.58 | 91.16 | 100.8 | 69.85 | 38.86 | 21.01 |
| stdev | 0.82 | 0.76 | 7.77 | 5.4 | 3.8 | 2.47 | 1.34 | 1 |

LwM2M appears to introduce a higher latency compared to amqp, even though it is based on UDP while the latter is based on TCP. Our estimation is that the node.js support for LwM2M is not optimized since the corresponding java LwM2M implementation for the client MS presents much better latency in its integration with a node.js server MS. (avg: 3.34, max: 49.14, stdev:2.81). To have a measure of comparison for the overhead that introduce the various MS integration mechanisms we note that the function call overhead is in the range of a few nanoseconds (ns). This is a convincing argument for avoiding the use of microservices at very low level of functionality such as function blocks or even operations such as heat and mix in the case of smart silo. Our proposal is to avoid the use of microservice containers for the development of primitive microservices since this introduces a high latency in integration. Instead cyber-physical components of the industrial system, such as smartSilo, can be implemented using traditional well proven technologies and expose their functionality as microservices using IoT technologies, as presented in [26].

D. The CPMS Architecture

For a traditional plant machinery of the manufacturing domain to be integrated into the microservice and IoT-based manufacturing environment, it should be transformed into a CPMS that provides a RESTful interface. We have adopted the OMA LW2M application layer protocol, which is implemented on top of CoAP, (an MQTT based implementation also exists) to provide an IoT-compliant interface for the CPMS, as shown in figure 4. IPSO objects were adopted to address interoperability requirements among

and transforming it to a smart unit that is able to either process, or transport, or store energy, material, parts, sub-products and products. A primitive cyber-physical MS (PrimitiveCPMS) has its own dedicated mechanical part (MechanicalUnit), that is completely under its control. However, the developer may decide if specific parameters of the physical part will be readable from the environment. This is supported by the provided interface of the CPMS (itsProvidedIf). Required interfaces (itsRequiredIf) capture the dependencies among MSs. Microservice Interfaces can be implemented by the Interface construct of OO IEC 61131 [28], which is supported by commercial tools, e.g. CoDeSys 3. Primitive cyber-physical microservices are implemented by real world entities which we call Industrial Automation Things (IAT). An IAT may implement more than one CPMS, as is the case of the processing unit IAT of the Festo MPS system [19], which hosts three CPMSs, the rotating disk, the drilling machine and the checking machine CPMSs.

Composite cyber-physical microservice is the microservice that offers its functionality by coordinating (directly or indirectly) the functionality of at least one primitive CPMS. Composite CPMSs implement functionality for either processing, and/or transporting, and/or storing material, parts, sub-products and products. The operation of composite cyber-physical MSs depends on the availability of the utilized primitive cyber-physical MSs with which it is coupled in time, that is another differentiation from software microservices.

C. Microservice orchestration overhead

Microservices interact via messages. In this work, the LW2M IoT protocol is adopted for their interaction. The orchestration inter-service interaction pattern is adopted for the construction of the composite cyber-physical microservice. The same interaction pattern can be used for the development of the cyber part of the primitive CPMS. However, in this case, to avoid performance overhead at this level of physical to cyber integration, where real-time constraints should be met, low latency communication mechanisms, such as the operating system’s IPC mechanisms, should be used. In this case, the benefit of scalability in microservice integration is partially lost, since a redeployment of a microservice to a different node requires development time modifications. Support from the microservice container to IPC transports in case of MS integration in the same node will provide a solution to this problem. As an indication of the performance overhead that is introduced by the different integration mechanisms for microservices, Table I presents performance measurements expressed in ms, regarding the latency introduced by communication mechanisms adopted in various levels of microservice integration. The Table captures the round-trip time for the Execute operation of the LW2M for the case that the plant process composite CPMS (liqueur generation process type A - lgpA) was deployed on the local cloud (fog), and more specifically on a workstation equipped with an Intel i5-4590 CPU running at 3.3 GHz and 8 GB of DDR3 RAM, running Ubuntu 16.10 64-bit OS and Java JRE 1.8.0_131. Raspberry Pi 3 Model B connected to a router is used as node for the implementation of the primitive CPMS. Node.js is used as a platform for the development of the IAT controller. Node.js is single threaded so it perfectly matches with the scan cycle model used in manufacturing. NodeRED (https://node-red.org/) was used for a user-friendly specification of the composite CPMS, following a process-driven approach [13].
different microservices. The IoTwrapper is the software layer that transforms the legacy interface of the cyber part of the plant machinery to an IoT-compliant one. It transforms the conventional plant machinery to an IoT-compliant microservice. We found the adaptation process too complicated for the Industrial Engineer and this was the motivation to use MDE to automate its construction.

For the specification of the IoT-compliant interface of the CP microservice, the LwM2M provides an object model that is based on the concept of Resource. This model focuses only on the modelling of the interface. On the other side, the traditional cyber-physical component, whose part is the plant machinery, has been specified with an object model that also specifies its interfaces. UML and SysML, the de-facto standards for software and system engineering, are commonly used for such specification. Thus, we have two models; one focuses only on the IoT-compliant interface description, and the other on the modeling of the whole cyber-physical MS including its interface, which cannot however be specified in an IoT-compliant way.

To address the above problem, we have defined the IoT layer on top of the cyber-physical MS layer of the extended MIM Architecture, as shown in Fig. 2. For the definition of the modeling space of this layer the basic constructs of the LwM2M object model were formalized using UML as shown in Fig. 5, that captures the LwM2M communication protocol interface. In this way projecting the cyber-physical MS layer model of cyber-physical manufacturing system to the IoT layer (Fig.2) we get the IoT compliant interface for the cyber-physical microservices of the system, as well as, for the system as a whole. UML was adopted as base for the transformation process between the two layers, and the UML4IoT profile was extended to implement this projection.

IV. THE PLANT PROCESS AS MICROSERVICE

Plant processes, such as the liqueur generation processes of various types, e.g., lgpA and lgpB of the Liqueur Plant case study [21], utilize directly or indirectly functionality provided by primitive CPMSs as well as computational services provided by traditional MSs, to provide a higher layer functionality required at the process level of the plant, as shown in Fig. 1. Thus, plant processes are realized as composite CPMCs. Chunks of functionality at the plant process layer that involve more than one CPMS are also modeled as CPMSs to have a modular and flexible process layer implementation. The CPMS transfer liquid from source silo to destination silo is a classic example of a CPMS.

A plant process is specified as an orchestration of functionalities offered by plant units, thus, the corresponding microservice that realizes the plant process is defined as orchestration of CPMSs. Several notations are used for service orchestration with the goal to be usually twofold, flexibility and responsiveness. Flexibility means to adapt to changing requirements in production, and responsiveness to respond to the physical plant stimulus meeting the deadlines that the plant units impose. The objective of the proposed approach is to fulfill both requirements. Responsiveness is addressed at the primitive CPMS level by encapsulating the mechanical unit control and coordination logic in the MS level, close to the physical plant unit. Flexibility is achieved by several means. As a first step, plant processes are implemented as dynamically deployable MSs, which are executed in a MS container that supports run-time reconfiguration, e.g., OSGi [13]. Moreover, plant processes are designed and implemented independent of specific resources. This allows a plant process, i.e., a composite CPMS, to dynamically acquire at deployment and even at run-time, the available CPMSs, which are required to fulfill its goals.

The plant process developer defines the plant independent model (PIM) for the process, i.e., she specifies the process in a plant independent manner. PIM specifies the operations that should be performed without using operations that depend on the plant configuration. For example, operations such as fill, empty and transfer, for the case of liqueur plant, have to do with the plant configuration and are not included in the PIM model. These operations will be inserted in the model in the next phase when the PIM will be transformed to a plant specific model (PSM), i.e., a specification for the process that is customized to the specific configuration of the plant. If, for example, the heating operation is not supported on the current silo, its content should be transformed to the silo that offers this functionality, an action that transforms the PIM to PSM.
A. PIM to PSM transformation

The transformation of the PIM to PSM can be performed manually by the control engineer. The development environment may support this operation utilizing the service discovery functionality of the framework. During this step, the control engineer may utilize the ability of the execution environment to automate parts of this transformation during run-time and more specifically during the instantiation of the process MS. During this process, the system will check for availability of primitive CPMSs providing the physical operations and satisfying the prerequisites of using them and instantiate the process MS reserving the required CPMSs. An alternative is for the system to postpone the reservation of resources up to the time they are required. This functionality of the framework supports a better use of the plant’s resources and allows a more flexible process implementation. The microservice description is a prerequisite for the realization of the PIM to PSM transformation.

B. Cyber-physical MS description and discovery

A primitive cyber-physical MS, such as the SmartSilo, has several exposed resources provided as services, as for example heat and mix. These services will be utilized for the realization of composite cyber-physical MSs, as for example the transfer liquid from source silo to destination silo. To address the interoperability requirements the IPSO smart objects have been adopted for the modeling of the resources exposed by CPMSs. Moreover, for the framework to support service discovery during the development time but also during run-time an efficient description is required for the MS and the operations that the MS implements. We have complemented the IPSO smart objects by RESTdesc descriptions of the offered plant operations and the MSs’ states. RESTdesc is a machine-interpretable functional service description format for REST APIs [24] that exploits HTTP vocabulary and Notation3 (https://www.w3.org/TeamSubmission/n3/) to enable the machine to discover and consume Web services based on links, similar to human browsing strategies [25]. N3 extends the Resource Description Framework (RDF). It is based on Statements, which are triples consisting of a Resource, a Property and the value of the Property, represented by URIs and serving as subject, predicate and object, respectively. For example, the triple local:heat a lps:Service of Fig. 6 defines heat as a Service (a is an abbreviation of N3 for the rdf:type property) and the rdfs:label instance of Property is used to define a human readable name for the resource. Properties are also used to express attributes of a resource or a relationship between two resources. RESTdesc descriptions include a set of preconditions and a set of postconditions, indicating that if the preconditions in the antecedent are true for a specific substitution of the variables, then an HTTP request will be feasible for the realization of a service by using URIs or request bodies associated with the same substitution. N3 statements may provide information about the functionality of a service, its inputs and outputs and information about Quality of Service (QoS) characteristics. For example, all heating services should have a common label “Heat”, defined by a corresponding ontology, but possibly different levels QoS regarding the maximum allowed heating temperature or the types of material that can be processed. Fig. 6 captures part of the description for a heating service which is labelled accordingly and has defined QoS characteristics, i.e. it accepts only input temperatures expressed in Celsius unit, it can heat up to 70°Celsius and it is destined for materials of liquid type.

The framework supports the discovery of MS using a service repository where the CPMSs of the manufacturing plant are automatically registered by their hosting devices (IATs). The CoRE resource directory [23] defined by the IETF CoRE Working Group is adopted in this work. It enables methods for discovering a resource directory (RD), as well as registering and looking up resource descriptions. Although in the manufacturing domain sleeping nodes and intermittent connection to constrained network are not the case, direct discovery of resources provided by devices may not be feasible in most smart environments [22]. The CoRE RD targets resource-constrained devices used in M2M applications and surpasses the problems that direct discovery imposes, by employing an RD which hosts accessible descriptions of resources held on servers. We use the CI-RD resource directory implementation of the californium.tools repository (https://github.com/eclipse/californium.tools) to be aware of the devices and services of the manufacturing plant.

Each device hosting CPMSs accesses the RD and sends a POST request through the registration interface. The message payload contains the list of resources offered by the device in the CoRE Link Format as well as the semantic and dynamic state descriptions of the provided resources. The RD lookup and update mechanisms allow the search and discovery of the exposed resources and the access to up-to-date information concerning resource descriptions. In the Liqueur Plant case study, its components, such as the smart silo, and smart pipe, register to the RD once activated and publish lists of the plant operations they provide, e.g. fill, heat, mix, along with their RESTdesc descriptions. The development environment or an agent, for the case of operation-time discovery, accesses the descriptions and looks for resources that offer the desired functionality for the realization of a composite CPMS, such as the liqueur of type A generation process (lgpA). The SPARQL query language for RDF (https://www.w3.org/TR/rdf-sparql-query/) enables the filtering of services which meet the process requirements. For example, during the development process of lgpB, the control engineer performs queries to identify Heat services with specific QoS characteristics, to specify and potentially utilize the entities that provide these services. Fig. 7 shows a SPARQL query for...
discovering heating services for liquid, with maximum allowed heating temperature greater than 50°C Celsius.

Fig. 7. Example query for the discovery of heat CPMS with specific QoS.

V. CONCLUSION
The potential of exploiting the microservice architecture along with IoT in the cyber-physical manufacturing systems domain is examined. A framework that exploits these technologies and utilizes MDE to simplify the development process is described. The framework has the cyber-physical microservice as a key construct for the modeling of the system. Performance measurements show that the application of the microservice architecture based on software microservices technologies, i.e., microservice containers and traditional microservice integration protocols introduce a high latency in the level of the cyber-physical component, i.e., smart machinery level, that is usually not acceptable in the industry. Traditional technologies can be used for the implementation of the smart machinery in the form of CPMS and expose its functionality through IoT. On the other side, microservices offer great flexibility at the plant process layer and are considered as a promising technology for manufacturing systems in the context of Industry 4.0. Thus, the CPMS is considered as the key construct for the modular development of flexible manufacturing systems.

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