Outcomes, Insights and Best Practices from IIC Testbeds: Smart Factory Web Testbed

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INTRODUCTION

In order to extend the usefulness of the published Testbeds in the Testbed Program of the Industrial Internet Consortium (IIC), the Testbed Working Group has developed an initiative to interview the contributors of selected testbeds to showcase more insights about the testbed, including the lessons learned through the testbed development process. This initiative enables the IIC to share more insights and inspire more members to engage in the Testbed Program.

This article highlights the Smart Factory Web Testbed. The information and insights described in the following article were captured through an interview conducted by Mr. Joseph Fontaine, Vice President of Testbed Programs at IIC, with Dr. Kym Watson, Principal Scientist and Deputy Head of Department Information Management and Production Control at Fraunhofer IOSB. Kym is an active member in the IIC where he has been serving as co-lead of the Smart Factory Web Testbed and is a key contributor to the Testbed Working Group. Kym co-chairs the IIC Distributed Data and Interoperability Management Task Group. In May 2018, Kym was recognized by his peers and bestowed the IIC Testbed Award for his leadership and contribution to the Smart Factory Web Testbed. His nomination indicated the importance of improving manufacturing order fulfillment and cited Kym's technical expertise, support and advancement of the smart manufacturing activities within the IIC.

SMART FACTORY WEB TESTBED – FROM CONCEPT TO REALITY

The Smart Factory Web Testbed aims to set up a web-based platform to allow factories to offer production capabilities and share resources to improve order fulfillment in a much more flexible way than is currently possible with available technology. It seeks to provide the technical basis for new business models, especially for small lot sizes, with flexible assignment of production resources across factory locations. This testbed is designed, in particular, to be a step towards establishing a marketplace for manufacturing where one can look for factories with specific capabilities and assets to meet production requirements. Factories offering those capabilities can then register to be located and participate in the marketplace.

This requires up-to-date information about the capabilities and status of assets in the factory. The characteristics of the products—availability, quality, price and so on—provides a basis for possible negotiation between competing offers.

For this application to work, international standards such as OPC Unified Architecture (OPC UA) and AutomationML are needed to link factories into the Smart Factory Web in order to provide information about the factories in a standardized way. This innovation enables production facilities to offer their services in a global market business and adapt their production in a very efficient way. The Smart Factory Web Testbed enables cross-site usage scenarios with secure Plug & Work functions and data analytics. It reduces Information Technology (IT) system integration and installation costs, allowing for faster engineering and ramp-up time of components, machines, plants and IT systems—improving upon the utilization of equipment, as well. The core functionality is to describe the capabilities of factory assets in a standardized way, to find assets with the necessary capabilities and to access status data about these assets so that they may be included in the overall order management.

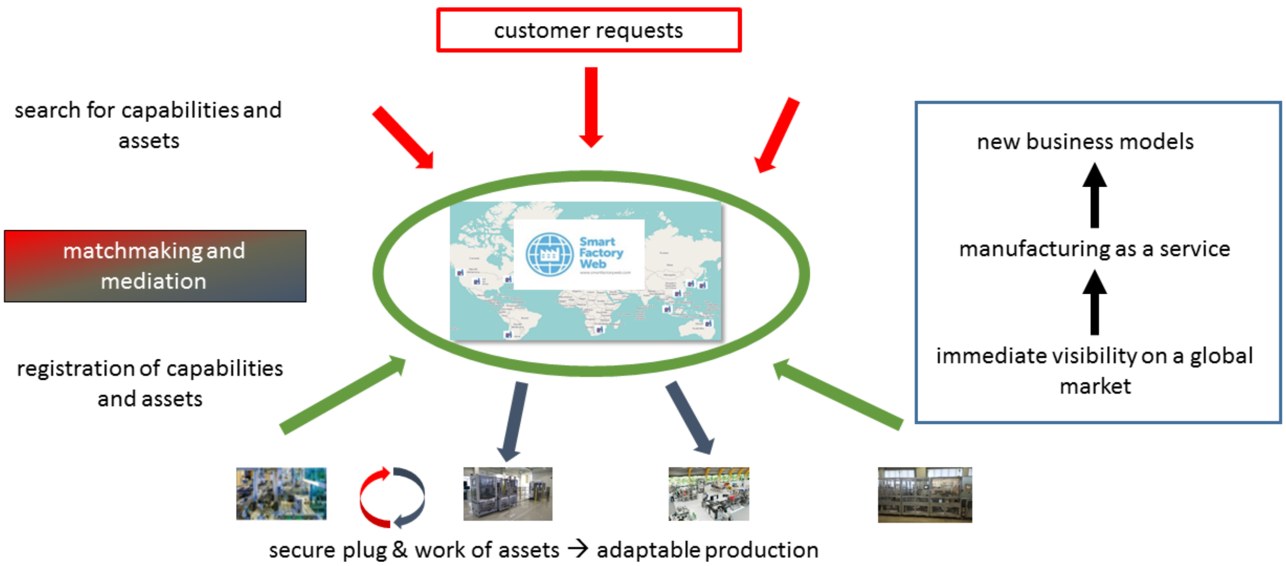

Figure 1: Smart Factory Web as a Marketplace for Manufacturing

The Testbed is directed mainly towards small-lot size environments rather than large manufacturers because companies working with larger line orders usually have their own supply chain management system and do not need to be as flexible and responsive due to the size of the orders. For smaller scale production, there are many more examples of where a moderate or smaller number of a particular part is to be produced, and machine capabilities need to be configured for this particular order.

To accomplish its goal, there are several areas of experimentation in the Smart Factory Web Testbed, including the engineering of automation systems for Plug & Work assets in a factory, flexible engineering, configuration of factory integration into Smart Factory Web and the Microsoft© Azure® platform, and the description of assets in AutomationML.

The Testbed's primary use cases involve manufacturers who seek to find a factory to produce certain parts. The manufacturer accesses the Smart Factory Web to find a factory with the right capabilities, and a potential target factory is identified. After negotiating with the target factory about delivery route, schedules, price and so on, an order can be placed. The target factory may need to adapt its production to meet the requested product specifications, and it wants to do this as efficiently as possible. Once the production order is finished, the factory provides the finished or partial product to the original manufacturer or to another element in the overall supply chain.

This usage scenario, *Order Driven Adaptive Production*, is a combination of the application scenarios "order controlled production" and "adaptable factory" as defined by Plattform Industrie 4.0 (PI4.0)[1]. In further detail, this scenario is split into the following sub-scenarios:

Sub-Scenario 1.1 Publish: Registration of Smart Factories

Realized in Phase 1: "Geospatial Mapping and Factory Information" with the help of AutomationML to describe factory capabilities and assets.

Sub-scenario 1.2 Find: Discovering Smart Factories

Realized in Phase 1: "Geospatial Mapping and Factory Information" to find smart factories registered in the Smart Factory Web with the desired capabilities best matching the order requirements.

Sub-scenario 1.3 Order: Management and Execution of Orders in Smart Factory Web

The workflows to broker, orchestrate and process production orders in the Smart Factory Web constitute this sub-scenario, but they are not part of experimentation in this testbed. A proof-of-concept implementation in the Smart Factory Web Testbed will handle the ordering workflows and modeling of supply chains. The proposed IIC testbed "Negotiation Automation Platform" led by NEC© will extend the concepts of the Smart Factory Web and take up this sub-scenario.

Sub-Scenario 1.4 Adapt: Adapting the Factory Production

Realized in Phase 2: "Plug & Work" to flexibly and efficiently adapt a production facility to meet order requirements.

Sub-Scenario 1.5 Bind: Smart Factory Web Asset Connectivity and Monitoring

Realized in Phase 3: "Data & Service Integration" to provide current information on product and asset status (including availability of free capacity) for exploitation in the Smart Factory Web, especially to support the discovery process and linking of supply chains through secure data exchange. The Smart Factory Web information model will be updated dynamically.

Sub-Scenario 1.6 Collaborate: Collaborative Engineering

To be realized in Phase 4: "Collaboration" to enhance the efficient adaptation of factory production with shared engineering workflows and software Plug & Work.

[11] https://www.plattform-i40.de/I40/Redaktion/EN/Downloads/Publikation/aspects-of-the-research-roadmap.pdf?__blob=publicationFile&v=10

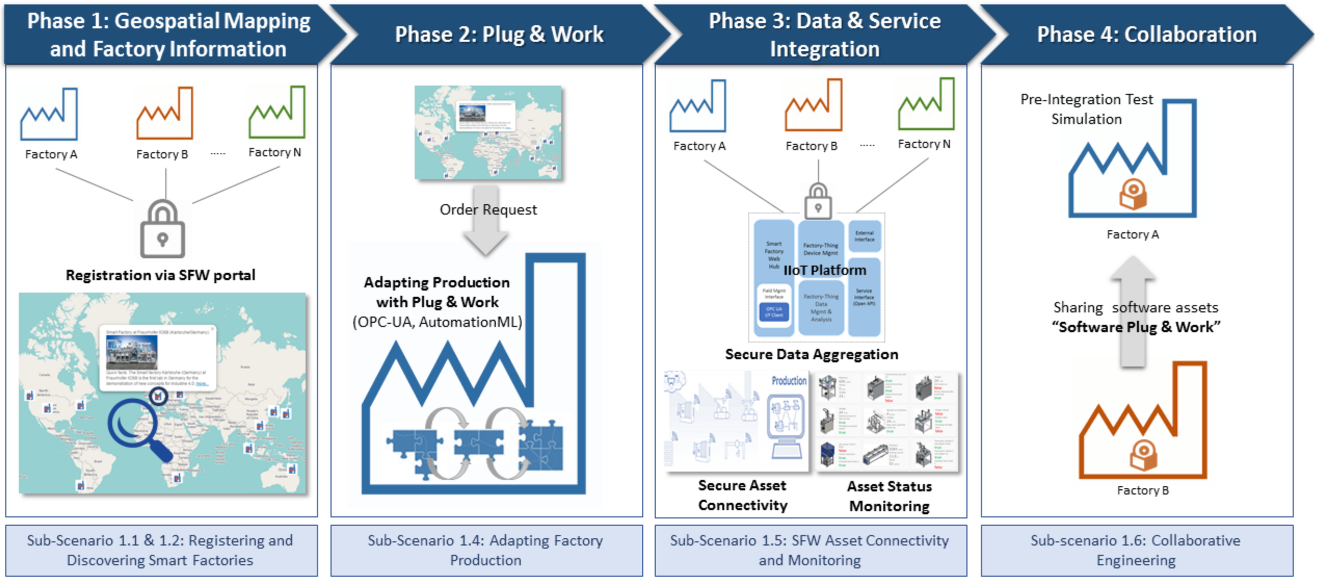

Figure 2: Phases of the Smart Factory Web Testbed

There are three primary technologies involved in the testbed. The first is the OPC UA, used to implement data communication between factories in the Smart Factory Web. Second, the standard AutomationML is used to describe the necessary information models—the semantics of the data transport from the factory to the Smart Factory Web. The other fundamental technology is the Smart Factory Web portal, a web-based information management system and application development environment which provides full support for access rights, work flows and ontology-based information models.

The primary experimentation for the testbed is working out an effective way of describing assets and capabilities and developing very efficient ways of achieving the overall software engineering where a new asset can be introduced. An asset can be described in terms of its capabilities but also in terms of its information model as interfaces. That asset must then be integrated into the information flow of a factory, the Smart Factory Web, and potentially cloud platforms such as Microsoft Azure. The testbed's core challenge lies in the software engineering processes, in an effort to make a factory adaptable. Other considerations include the electrical and mechanical interchangeability of a new device.

The testbed is deployed in model factories located in Karlsruhe and Lemgo, Germany and Ansan and Pangyo, South Korea. The model factories in Germany are operated by Fraunhofer IOSB and those in South Korea by the Korea Electronics Technology Institute (KETI). The two factories in Karlsruhe and Pangyo deal with handling, filling and transport. Both factories involve filling small bottles with either pellets or fluid, transporting these bottles with a small conveyor belt, and emptying the bottles—

with a few quality inspections. The Karlsruhe factory will look at implementing the (PI4.0) Asset Administration Shell for a number of assets in the next few months to validate the concepts of PI4.0. The model factory in Lemgo in northern Germany also involves handling and filling but on a larger scale including assembly within a versatile production facility.

Ansan's model factory is a large facility with real production equipment to accomplish tasks including the visual inspection of pistons from a local vehicle manufacturer's factory. The model factory in Ansan features a fully implemented digital twin of the manufacturer's production. There is a real production line where various parts are transported and inspected. A floor simulation model of the robot motions of the conveyor belt show how the engineering process is actually conducted. Therefore, if a change to the line would be needed, it can be done in the simulation environment (the digital twin) before going live, which would otherwise be a high risk. The Smart Factory Web Testbed strives to work closely with manufacturing and automation companies and eventually transfer its technology into real productive environments.

To date, the main deliverables of the testbed are documents describing the key concepts, standards application and implementation architecture of the Smart Factory Web. These concepts can then be adapted and adopted for use by a company. Another planned output of the testbed is the experience of how to describe asset capabilities, efficiently integrating assets into an overall software architecture. Additionally, the testbed is driving standards by providing feedback to the relevant standards bodies—OPC UA, AutomationML, and also standards work within the IIC and PI4.0. While other organizations are working in the area of asset administration, the Smart Factory Web Testbed strives to play a forerunner role in this area by tackling the whole combination of technologies involved.

Testbed Planning

The IIC ecosystem has played a significant role in the planning of the testbed. Regular presentations of the Smart Factory Web Testbed and resulting discussions with IIC members at quarterly meetings and special IIC events were important mechanisms which allowed for continuous discussions and constructive feedback about the Testbed's purpose and function. Participating in the IIC Member Pavilion at events such as IoT Solutions World Congress in Barcelona and Hannover Messe has led to high visibility of Testbed activities and a better understanding of the requirements and potential applications.

In establishing alliances for various extensions to the Smart Factory Web Testbed, the IIC ecosystem played an instrumental role. The IIC's collaboration with PI4.0 is enabling the realization of the I4.0 component concept for selected assets in the Smart Factory Web Testbed. An I4.0 component comprises an Asset Administration Shell (a digital representation) and the respective asset. Working with IIC member, Microsoft, the integration of factories into the Microsoft Azure platform led to visualizing factory process data. A new IIC testbed for the brokering of production and logistic services was proposed in conjunction with IIC member NEC's, the Negotiation Automation Platform. An alliance with IIC liaison, International Data Spaces Association (IDSA), brought the implementation of an IDS connector for trustworthy data exchange between factories and the Smart Factory Web portal. Furthermore, the IIC ecosystem fostered collaboration between PI4.0 and the IIC, facilitated the international dissemination of the benefits of standards in a testbed, and promoted work on the description of assets of IIC members.

There have also been benefits for the companies operating the model factories—Fraunhofer IOSB and KETI. Both organizations perform applied research and development for industry. Through the Smart Factory Web Testbed, they aim to improve and better market their own offerings in the field of IIoT and automation. In addition, the Smart Factory Web Testbed is a showcase for products and technologies of participating companies, enhancing their market opportunities. The network of companies taking part will form an 'innovation community' supported by KETI and Fraunhofer IOSB to identify and fill technology gaps by linking the knowledge and requirements of users, companies and research organizations. KETI and Fraunhofer IOSB advise companies on technology assessment and development of technology roadmaps. Furthermore, the Smart Factory Web Testbed has been integrated into training programs offered by Fraunhofer IOSB and KETI on industrial automation and security, including the application of OPC UA and AutomationML standards.

In choosing partners, it was important that the prospective organization was a leading innovator in IIoT in the manufacturing domain and a strong promoter of open standards. In addition, expertise with the standards used in the Testbed was required to participate.

IIC INTERACTIONS

The 3-tier architecture of the Industrial Internet Reference Architecture (IIRA) was applied in two places within the testbed: 1) in each model factory and 2) in the Smart Factory Web with gateways to the factories in the edge tier. The testbed has also adopted the general terminology used in the IIRA, a crucial step to facilitate clear messaging to the rest of the industry.

The activities of the Smart Factory Web Testbed have contributed to several aspects of the IIC. The Smart Factory Web Testbed is a candidate vehicle for an IIC-PI4.0 collaboration aiming to trial the PI4.0 specification *Details of the Asset Administration Shell* which defines how data exchange shall happen between Industrie 4.0 components based upon international standards. In addition, Fraunhofer IOSB is using testbed results and its own experience to contribute to the whitepaper "Digital Twin and Asset Administration Shell, Concepts and Application", of the IIC-PI4.0 Joint Task Group. The IIC DDIM TG (Distributed Data Interoperability and Mananagement Task Group) is working on a whitepaper to be published in 2019 dealing with IoT information models for semantic interoperability and the characteristics of these models with the aim of proposing a meta-model. The information models and standards used in the Smart Factory Web Testbed have been contributions to the DDIM TG work. NEC submitted a research and development proposal related to the Smart Factory Web Testbed for the Japanese government which has been accepted. As part of this large national project, NEC has proposed the IIC testbed Negotiation Automation Platform which extends the concepts of the Smart Factory Web Testbed platform and includes information models to describe assets and supply chains as well as AI methods for negotiation. The work of Fraunhofer IOSB will be carried out within the Fraunhofer Cluster of Excellence "Cognitive Internet Technologies".

Standards

The Smart Factory Web Testbed employs a plethora of noteworthy standards. When possible adaptions to a standard are identified, the testbed reports to the relevant standards body. This report may involve submitting a change request or undertaking an accommodating process, depending on the standards organization. Regarding Open Source projects for example, the Open Source communities can process comments submitted and incorporate changes into the latest releases of the software. The Smart Factory Web Testbed supports standards with Open Source Development as a way of trialing a standard and receiving practical feedback about the specification.

IEC 62541 standard OPC UA is used for the data transfer between automation devices within a factory, between different factories and between the factory and the Smart Factory Web Testbed. The standards work in OPC UA is supported by the Open Source project open62541 where Fraunhofer IOSB has made major contributions, see https://open62541.org . KETI will also be contributing to open62541 in 2019. In addition, Fraunhofer IOSB has developed the Fraunhofer Open Source SensorThings API Server (FROST). Both open62541 and FROST are deployed in the testbed, and these Open Source projects contribute to the maturity and onward development of the respective standards.

IEC 62714 standard AutomationML is used to describe the semantics of the data, which data will be integrated into the Smart Factory Web, and how that data is going to be visualized. The Smart Factory Web Testbed uses AutomationML to provide the basis for the automatic generation of OPC UA servers, following the standard Companion Specification OPC UA for AutomationML. Experience gained in the Smart Factory Web Testbed is fed back into the onward development of the Companion Specification.

One recent activity involved implementing OPC UA over an OPC UA publisher subscriber (pub sub) and running it over a Time Sensitive Network (TSN). The OPC UA pub sub is a relatively new aspect of OPC UA, and this implementation executed in conjunction with an IIC member helped to mature the specification of this OPC UA pub sub.

Certain areas of relevant standardization are not yet fleshed out in the industry but are needed to fulfill the overall use cases, such as the area of geospatial data, e.g., to consider environmental aspects as part of a smart factory. The Open Geospatial Consortium has standards in this area, but they are not yet fully integrated into the standards typically used in the manufacturing automation domains, i.e., OPC UA and AutomationML. Another gap lies in the information models available for IIoT. While there is progress in the companion standards being worked on for OPC UA, the development process is ongoing.

A standard of Open Geospatial Consortium called SensorThings API is becoming popular in the IIoT domain: The Smart Factory Web Testbed uses this standard to easily integrate additional sources of data, particularly sensor data, into a Factory Web. The oneM2M standard is being used by KETI, though it is not central for the overall Smart Factory Web concept. This standard can be added into the Smart Factory Web if devices within factories support oneM2m. There are standards used from the PI4.0 area which describe reference architectures for service architectures.

More work is also needed in the specification of the Asset Administration Shell from PI4.0, a digital representation of an asset by which modular and interoperable digital twins may be built according to the Industrie 4.0 concepts. The Smart Factory Web Testbed hopes to provide support to this standardization work. Additionally, semantic descriptions of asset capabilities are an important aspect of standardization still needed in the industry, but there is further work to be done in this area.

TESTBED RESULTS

There are four phases in the Smart Factory Web Testbed:

- Phase 1: Geospatial Mapping and Factory Information
- Phase 2: Plug & Work
- Phase 3: Data & Service Integration
- Phase 4: Collaboration

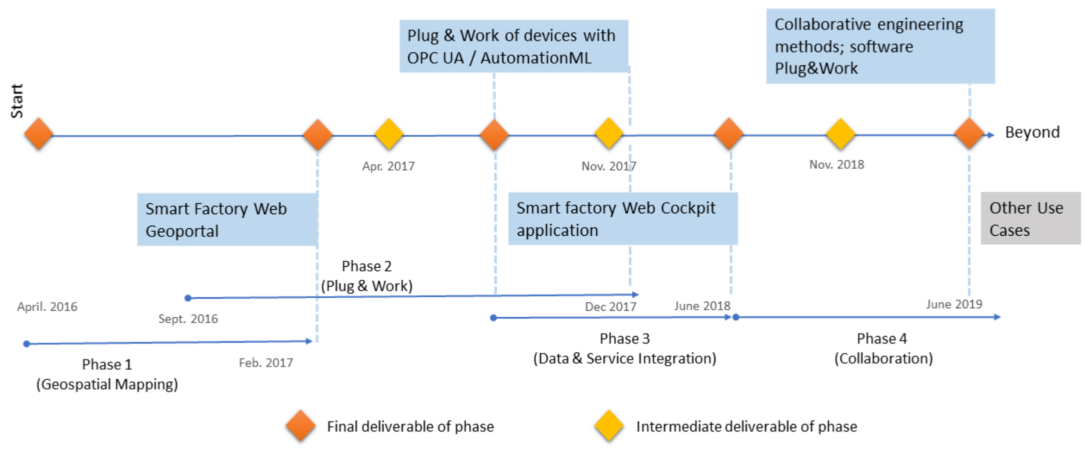

Figure 3: Timeline of the Smart Factory Web Testbed

The Testbed's architecture and experiences gained in the testbed over all phases will be documented in a technical design report to be published as a whitepaper in 2019. The Testbed team plans to extend the report to describe the work being done in the Digital Twin/PI4.0 Component Testbed, a project under the IIC-PI4.0 Joint Task Group and on the IDS connector.

Functionally, the first three phases have been completed up through the Data & Service Integration. Phase 4 involves the collaborative software engineering of these systems. There will be more work on the overall system architecture to include new developments with the Asset Administration Shell, as well as extensions of the Smart Factory Web Testbed to support the Negotiation Automation Platform from NEC. Though this work has started, the specifications are still a work in progress. Currently, the collaborative software engineering phase is ongoing—intensifying the work on the Asset Administration Shell, on the extension of the Smart Factory Web platform for other testbeds, and for the work with IDSA.

The technical report highlights the description of assets in AutomationML, covering:

- Their capabilities based on an ontology (to discover and integrate them as resources in a factory or supply chain),
- The definition of data to be sent to Smart Factory Web and Microsoft Azure through OPC UA or SensorThings API utilizing the automatic generation of OPC UA aggregation and FROST servers and
- The visualization of asset data in Smart Factory Web and Microsoft Azure.

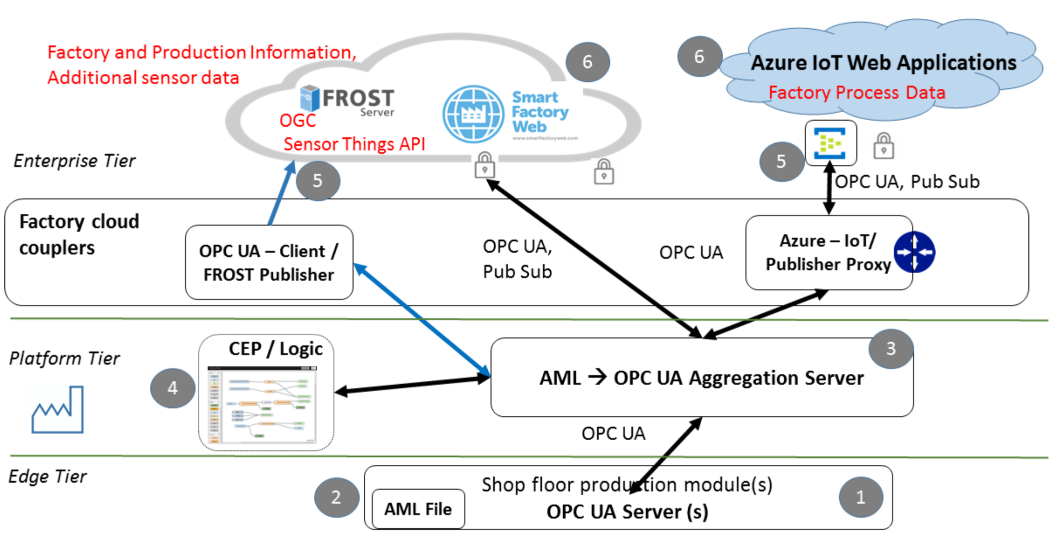

Figure 4: 3 Tier Architecture for Factory Integration. Abbreviations AML: AutomationML, CEP: Complex Event Processing, OGC: Open Geospatial Consortium, FROST: Fraunhofer Open Source SensorThings API Server

The results of Phase 3 are also summarized in the paper *Cloud-based Plug and Work Architecture of IIC Testbed Smart Factory Web* from the 2019 IEEE 23rd International Conference on Emerging Technologies and Factory Automation (EFTA)[2].

Because the focus for Phase 4 is on collaborating to achieve the necessary software engineering to integrate factories together, the engineers of the various factories and assets in the factories are needed to provide data and semantics of their assets in a way that can be integrated into a cloud—Smart Factory Web or Azure.

There has been a notable level of interest in the Smart Factory Web Testbed coming from the industry, resulting in several types of customer engagement. Fraunhofer is currently working to form advanced, leading-edge models and move them into the industry. To enable this entrance into the field, the Smart Factory Web Testbed has had ongoing discussions with industrial companies to transfer research and development results from the experimental environment. This would entail setting up a type of Smart Factory Web for the production environment.

In addition, Fraunhofer is transferring general knowledge and training as part of its mission, and the Testbed has already conducted a number of training exercises on OPC UA and AutomationML for the industry. The Testbed has also transferred this knowledge to KETI, who are now conducting similar training sessions for Korean companies. Another example of customer engagement is consultancy work on how to design factories of the future and how to set them up to include new emerging technologies.

This area represents a challenge because there are so many new technologies arising, and it is difficult for anyone to assess whether these technologies will have a real impact and can be relied upon for the next fifteen years. In addition, the testbed must be able to transfer these technologies to client applications, help set up the necessary software environments and concepts, and take a multitude of steps to implement the Smart Factory Web or aspects of the Smart Factory Web in the clients' own workflows. It is crucial to increase the level of understanding and skills about certain technologies—trust in those technologies needs to be established so that there is a sufficient level of proven experimentation and best practices on how to apply the technologies. This level of trust is necessary before using these technologies in critical manufacturing applications where large production costs, and employee well-being, is at stake.

One of the major lessons learned from the Testbed is that open interfaces based on standards are essential to realizing a system architecture that can be adapted to changing requirements and technologies with a

[22] Heymann, S.; Stojanovic, L.; Watson, K.; Nam, S.; Song, B.; Gschossmann, H.; Schriegel, S.: "Cloud-based Plug and Work architecture of IIC Testbed Smart Factory Web". Proceedings of 2018 IEEE 23rd International Conference on Emerging Technologies and Factory Automation (ETFA), Torino, Italy, September 4th to 7th, 2018

reasonable effort. The new version of the technical design report will contain best practices and how to set up the overall system architecture. It will be a blueprint comprised of advice on how to accomplish this integration in a sustainable way.

EXPERIENCE

The Smart Factory Web Testbed derives different forms of business value from participating in the IIC Testbed Program. The testbed has been able to procure new projects in the IIoT domain based on the experiences gained, as well as the marketing support given by the IIC. Visibility and the number of clients in major IIC regions—Europe, North America and Asia—have noticeably grown. From the perspective of the IIC member companies, it is hoped that there will be value for new clients to be able to apply some of the key technologies from the testbed more efficiently and with a higher degree of confidence.

The Smart Factory Web Testbed would offer three pieces of advice to other testbeds and companies considering an IIoT implementation:

1) Follow open standards as far as possible—this is a prerequisite to the second piece of advice.
2) Develop a sustainable, robust and flexible implementation architecture where one can make adaptations and demonstrate new technologies as easily as possible.
3) Ensure that there are sufficient accompanying projects to maintain synergy, funding and stakeholder commitment—this will bring the testbed from concept to reality and help maintain it over a period of several years.

CLOSING

Having been through this testbed process and coming to the end of Phase 4, the Smart Factory Web Testbed team finds that they did not encounter many major surprises in the technical area, but were surprised by their findings in the area of marketing. The level of interest in Smart Factory Web for various application scenarios involving cross-facility collaboration is much more prolific than originally expected. There are many different ideas and opportunities to transport these ideas to different applications, especially where some form of cross-organization or cross-facility collaboration is needed.

The Smart Factory Web Testbed embraces the spirit of why the IIC offers its testbed program. The level of effort put into the Testbed correlates with the high level of output and discovery, and the Testbed continues to be a model example of innovation in the IIoT domain.

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