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Facilitating model-based design of cyber-manufacturing systems

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Abstract

Manufacturing companies need to go digital. Although this sector leads in automation adoption, some companies struggle to explore emerging innovations such as Cyber-Physical Systems, Digital Twins and "servitisation in manufacturing". The equipment required to deliver production systems typically combines physical and software components, yet digital innovations require investing in new models and tools, and training in model-based design. In this paper, we report on a new collaboration platform fostering the ability to experiment with digital innovations using a sandbox environment, accessible online via the user browser, and with good acceptance in small experiments by members in the manufacturing community.

Keywords: Model based development; collaboration platform; cyber-physical systems; digital twins; sandbox

1. Introduction

Manufacturing companies produce goods in large scale using product lines, adopting computation and developing innovation in the automation and robotics field. The equipment required to deliver efficient production systems combines mechanical, electrical, and software components. Normally, the equipment's lifecycle is composed of lengthy development phases (in the order of decades), starting from conception and planning, going through design and engineering, up to construction, validation, verification and commissioning.

During commissioning, both the equipment's operator and vendor cooperate through contracts to maintain optimal performance of equipment at a minimal cost [1]. This imposes several constraints on the new parts and on the upgrades of both hardware and software, which in turn limit the potential for adaptation of equipment to products differing substantially from the original intended production idea.

However, the market is changing. Customers' expectations change rapidly, leading manufacturers to the need of making their product portfolios suitable, integrate them in systematised solutions and adapt the related production systems in a more flexible way. Platforms, with embedded methods and tools, have recently been proposed in the literature for multiple purposes. Landahl et al. [2] developed a dynamic platform modelling approach that supports concurrent product-production reconfiguration. Other researchers proposed an engineering platform integrated with specific methods [3, 4] and tools [5] to develop Product-Service Systems (PSSs) with a joint focus on both customer's perspective and company's internal performance, exploiting the knowledge related to both the side with an entire product lifecycle approach [6].

All of these solutions were aimed at supporting providers to intercept the new needs arising from the market and propose new integrated solutions capable to dynamically meet at the same time the providers' technical requirements and the customers' needs. Such PSSs are supposed for traditional product manufacturers to be both a means to provide strategic market opportunities [7, 8] and a countermeasure to standardisation and mass production [9].

As a result, continuous development and evolutions of production systems throughout the solutions' entire lifecycle become a necessary paradigm change, especially to sustain a position in the future Industry 4.0 domain [10, 11], splitting into nine categories of innovative digital technologies [10]. In this digital context, data- and observation-driven adaptation is the

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strategic key to support the decision-making process to reconfigure production systems online [12, 13].

1.1. The need for Model-Based Design

The paradigm change requires a significant adoption of computation in production and the achievement of the higher-levels of the Cyber-Physical Systems (CPS) 5C (connection, conversion, cyber, cognition, and configuration) architecture proposed in [14], where systems self-optimise and operate at the full digital-twin level. Self-optimising CPSs and Digital Twins increase the role of software in manufacturing by requiring models of the system at hand, i.e. tools and expertise in Model-Based Design (MBD) [15].

The investment in models and tools open an opportunity to explore "servitisation in manufacturing" [16, 17, 18], a paradigm where manufacturers shift to offer product-related services. Service contracts generate more steady revenue compared to the cyclical product business [19][1] but, in general, organisations in this domain struggle to drive servitisation [20], because the introduction of the new services incurs a higher cost without proportional returns [21, 22].

Small and Medium Enterprises (SMEs) in particular face several barriers when adopting model-based driven models and tools, servitisation [23] and digitalisation in general [24, 25][2]. Suddenly, the traditional and certified tools in the plant require a digitalisation upgrade associated with different sets of skills [26, 27]. In addition, to develop higher levels of smartness (as the case of a digital twin producing online optimisation), SMEs need to go beyond their short innovation cycles and to use MBD assets which are associated with substantial investments: tool licenses, model development, and training. Furthermore, the decision on which tools to use involves negotiations between providers and adopter considering costs, effort, and expected benefits, which poses another entry barrier in itself.

To lower the entry barriers of SMEs to digitalisation [28, 29], servitisation and MBD and to address the cross-cutting challenges, the European Commission, also under the Smart Anything Everywhere initiative, has financed the HUBCAP [30] (Digital Innovation HUBs and CollAborative Platform for cyber-physical systems) project. It provides a one-stop-shop to SMEs wishing to embrace digital innovation using MBD technology. The offering encompasses:

1. a platform with a cloud-based sandbox solution with pre-installed models and tools,
2. a decentralised network of Digital Innovation Hubs (DIHs) providing access to training and expertise in MBD, and
3. an open call programme to attract and foster partnerships among SMEs.

HUBCAP belongs to the stream of those initiatives launched by EC and aimed to properly support the products upgrade, processes improvement and business models adaptation to the digital age leading to the creation of Digital Innovation Hubs (DIHs) in the frame of Digitising European Industry (DEI)[3]. The project started January 2020, and it is developing a new community to lower the entry barriers for European SMEs looking to adopt MBD in the development process of their CPSs. The project is co-financed by the Smart Anything Everywhere initiative and has a € 3.2 million equity-free fund for SMEs interested in joining the community. In this paper, we provide examples of the features and advances that may provide solutions to some of the challenges faced by players in the manufacturing community when faced with a need to adopt models, tools and digitise their processes.

This paper is structured as follows. Section 2 presents the HUBCAP platform. Section 3 raises its strengths, discussing its relevance mainly for the manufacturing industry. Finally Section 4 provides our concluding remarks.

2. The HUBCAP platform

In HUBCAP, users can access MBD tools and models using a web-portal, which provides users with a collaboration environment inspired by Enterprise Social Software [31]. It supports both "Access to" and "Collaborate with" services, providing companies access to the latest knowledge, expertise and technology during their digital transformation paths toward piloting, testing and experimenting with MBD in a "test before invest" manner.

Technically, HUBCAP provides industrial players, technical developers, and decision makers access to MBD assets in the form of two catalogues listing available models and tools, as illustrated in Figure 1. Users are given the opportunity to experiment with tools and models in the platform using the sandbox concept, which is accessed through a browser connection.

The knowledge-driven services, complemented by the collaborative and innovation side of the platform, are intended to create a virtual environment where providers and consumers of digital technologies are not just matching assets and needs, but they are collaborating together towards joint innovations. Therefore, providers are able to install tools and models, launch the sandbox, and to invite consumers to their sandboxes as guest users. Both provider and users have access to the standard interfaces of the underlying remote operating system and to co-create/experiment with assets.

The accounts in [30, 32] present the full details on the platform and sandbox concepts, in addition to the underlying cloud

[1] See also A. Z. Bigdeli, "Annual Manufacturing Report 2016," UK, 2016.
[2] See also European Commission, "Digital Innovation Hubs - Smart Specialisation Platform" 2020. [Online]. Available: https://s3platform.jrc.ec.europa.eu/digital-innovation-hubs-tool. [Accessed: 25-Nov-2020] and European Commission, "Digital Innovation Hubs in Smart Specialisation Strategies. Early lessons from European regions," 2018.

[3] See European Commission. Smart Anything Everywhere – Digital Innovation Hubs – Accelerators for the broad digital transformation of the European industry, 2018. Available from: https://ec.europa.eu/digital-single-market/en/news/communication-digitising-european-industry-reaping-full-benefits-digital-single-market. European Commission. Digital Innovation Hubs – Smart Specialisation Platform, 2020. Available from: https://s3platform.jrc.ec.europa.eu/digital-innovation-hubs-tool.

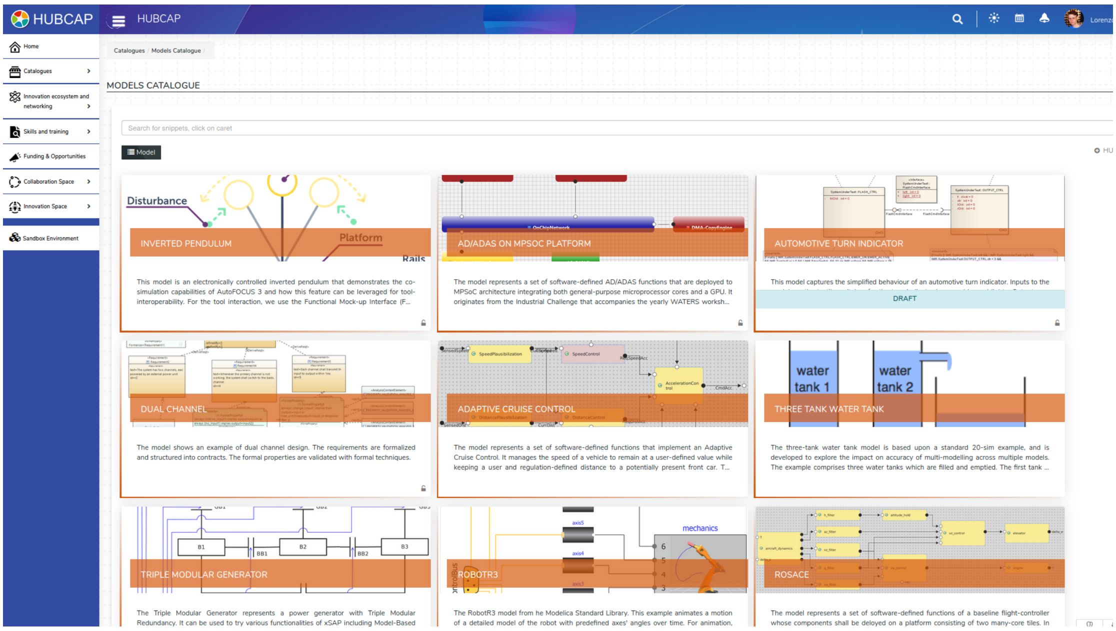

Fig. 1. Depiction of the catalogues of models ready to use.

infrastructure and operational concerns in terms of security and performance.

2.1. The HUBCAP Sandbox

The sandbox concept was inspired by the results of the INTO-CPS project [33], where several MBD tools were integrated into a single application [34] aggregating the different models using an FMI-based co-simulation orchestration engine [35]. In such a typical MBD setup there are three classes of assets:

- models, which are mathematical or formal abstractions of system elements (components or subsystems);
- tools, which are software packages and their dependencies that enable the development, analysis, and simulation of models; and
- Operating Systems (OSs), which refers to a software environment providing libraries and dependencies needed to run the tools.

A sandbox is implemented as an isolated set of Virtual Machines (VM)s (each one running at least one MBD tool) that interact with each other sharing a virtual dedicated subnet and a dedicated Network File System (NFS) storage service. No interaction is permitted between the VMs belonging to different sandboxes. The sandbox capability is integrated with the DIHIWARE Platform and it includes middleware to manage and mediate the access to those cloud services. In addition, as many cloud service providers offer the capability to select a combination of hardware and operating systems, the HUBCAP Platform offers the user to select a combination of Operating System (OS) environments, tools, and models to run an experiment using the HUBCAP sandbox feature.

The sandbox service is outlined in Figure 2. The DIHIWARE Platform is enhanced with a broker component (labelled as *Sandboxes Broker* in the figure), which hosts a web application mediating the access of different users (*Client 1* and *Client 2*) to the sandboxes they requested (*Sandbox 1* and *Sandbox 2* respectively). All the users will use an Internet browser to access the tools in the sandbox and all the interactions are mediated by the broker. The *Sandbox Broker* has access to the catalogues of different models, tools, and pre-configured OSs that are available, so an end user can simply pick a valid combination to request a sandbox. In addition to those catalogues, the *Sandbox Broker* keeps user information, such as the user's models (private copies of the model in the catalogue, which may have been modified by the user while using the sandbox) and the sandboxes the user created. This information is important to allow the creation of new sandboxes.

The operation of user requests and the sandboxing logic is provided by the *Sandboxing Kernel*, which is a component that interacts with the system *Hypervisor* to launch the different constituents of a sandbox, namely:

- *NFS* – Network File System providing storage in the form of shared folders where model files and tool outputs are placed.
- *VLANS* – Virtual networks restricting the communications of the VMs inside a sandbox to the set of VMs composing it and those only.
- *V.OS* – Virtual machines running the OSs supporting a tool, a remote desktop protocol to provide the clients access to the tool display, and other monitor and interoperability tools to operate the VM inside the Kernel.
- *Tools* – The tools running a model or a multi-model.
- *Models* – A mathematical/formal description of a component.

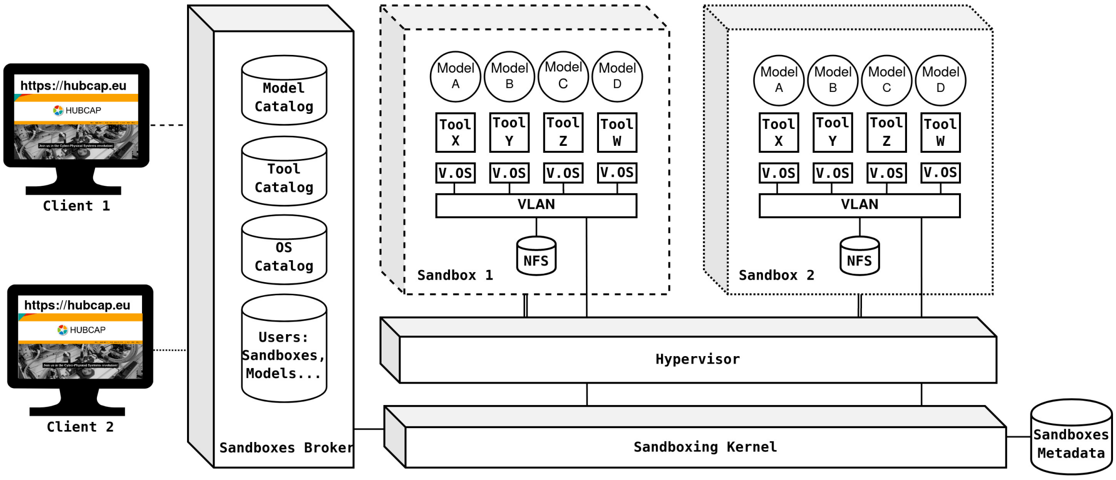

Fig. 2. The HUBCAP Sandbox architecture (taken from [30])

The operation relies on a database of metadata about the different sandboxes (the *Sandboxes Metadata* component in the figure). This component stores and keeps track of the sandboxes' states (e.g., running, suspended) and user ownership of the resources. It is worth highlighting that the Kernel has direct network connections to the Sandboxes' VLANs.

The platform enables users to pick models and tools into a cart and launch them in a cloud environment, which caters for the different technicalities required by the tools and models, and allows several users to co-develop a model by sharing the user interface of machines hosted in a cloud environment and accessible via a web browser. In Figure 3 provides a screenshot of an example tool running inside a HUBCAP sandbox. In it, we see the embedded remote desktop access to the cloud solution providing the appropriate runtime for the tool and model chosen. The figure also shows the sharing facilities in the bottom right corner.

3. Relevance to the Manufacturing Community

The initial community experiments with the platform were performed by assets in the portfolio of the DIH network, and by integrating the assets from a group of initial SMEs in the community. The results of the deployment of the SME assets are documented as short video demos[4], and we expect the conclusion and results from the initial experiments to push the sandbox prototype forward in the development iterations to happen in the years ahead.

The results show that the platform is suitable for the requirements of SMEs providing tools of relevance to the manufacturing community, e.g. plant simulation, virtual reality, and 3D visualisations. One example of a tool supporting the manufacturing domain users can access through the HUBCAP platform is the DDD Simulator by TTS-Technology Transfer System S.r.l. a MBD tool used to provide solutions to manufacturing companies. The tool was packaged inside a HUBCAP sandbox, by TTS, one of the seed SMEs belonging to the HUBCAP consortium. The DDD Simulator addresses digital twin development and simulation all along the factory life-cycle: from simulation-based design, commissioning to real data analysis and monitoring. TTS developed a related discrete-event simulator (DDD-Simulator), models for dedicated process stages (DDD- Machine) and a supervision unit (DDD-Supervision), to be integrated, offered and used via the HUBCAP collaboration platform. A free licence for the DDD-Simulator environment has been provided by TTS for the duration of the project providing a well-defined licensing framework for potential adopters experiments.

Regarding usability, during the experiment, the user interacted with a remote desktop of a virtual machine hosting the DDD Simulator without expertise beyond the average browser and operating system. On the right-hand side of the figure, the Sandbox middelware displays controls/buttons that a user resources to while interacting with a sandbox. Manufacturing companies can use the Sandbox features to acquire training and the models required to add smartness to cyber-manufacturing system, eg: digital twining the physical asset with a digital model.

Overall, the HUBCAP platform features MBD to the CPS developers in general, yet it was envisioned with the manufacturing field in mind as well, and it has attracted several providers in the field. The first open call providing funding for European SMEs to deploy assets in the HUBCAP catalogues in July 2020 approved funding to 21 individual SMEs from 12 countries in the European region and at least 6 companies selected to provide models and tools within the manufacturing domain.

4. Concluding Remarks

This paper reports on HUCAP, an ongoing project, and its experimental online platform, that can be used by the members in the area of cyber-manufacturing domain to adopt MBD tools and assets and improve their product portfolios. The project fea-

[4] https://www.youtube.com/playlist?list=PLbVe239TJ_ZKWiD4FYZhW-GTJ21gAeR9o

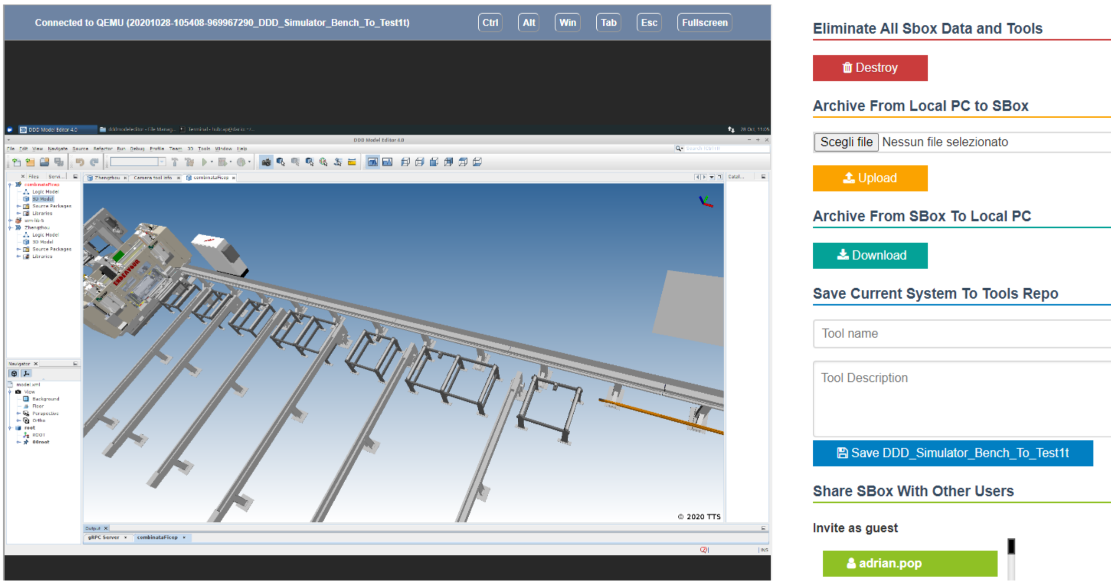

Fig. 3. Screenshot taken from the Seed SME experiments lead by Technology Transfer System S.r.l. (https://www.ttsnetwork.net/) an SME specialised in customised IT solutions for manufacturing.

tures a sandbox and a catalogue of ready-to-use tools and models. In addition, it establishes a network of DIHs building an ecosystem capable to connect different stakeholders to support the adoption of those technologies, especially in SMEs. The platform has been populated with assets from SMEs and the DIH network, and some of the initial experiments demonstrate the applicability of MBD in the area of manufacturing.

Additionally, the project features open calls to attract MBD assets, which have been attracting interest from partners in the manufacturing community. We expect the players in the manufacturing domain to find an advantage in its browser technology mediation, and expect some SMEs in the domain to adopt some of the assets available. Given its business-to-business characteristic, the cyber-manufacturing domain has the potential to enable model and tool providers to extend their brands and enrich their product portfolio [36], and HUBCAP can play the facilitator role, where providers and adopter find matches and experiment assets hands-on see Figure 4.

Although the prospect of establishing a good synergy with the manufacturing domain, there are also limits that need to be overcome. The platform is currently not open to non-partners and required participation via the open call programme. The catalogue contents may not supply an arbitrary need, given that the practice in MBD is the co-creation between operator and developers, and tools are specialised to suit the particular project's needs. We must also highlight that a lot of models need to be gathered on the platform and maybe also be better organized (per sector, per component, per product or through tags and labels) to meet most efficiently the requests coming from the manufacturing SMEs. Another limitation is the high degree of specialization of the HUBCAP DIH that will need to collaborate with other DIHs networks involved in the digital transformation process to enable its platform to maximize its outcome, in particular in the area of manufacturing.

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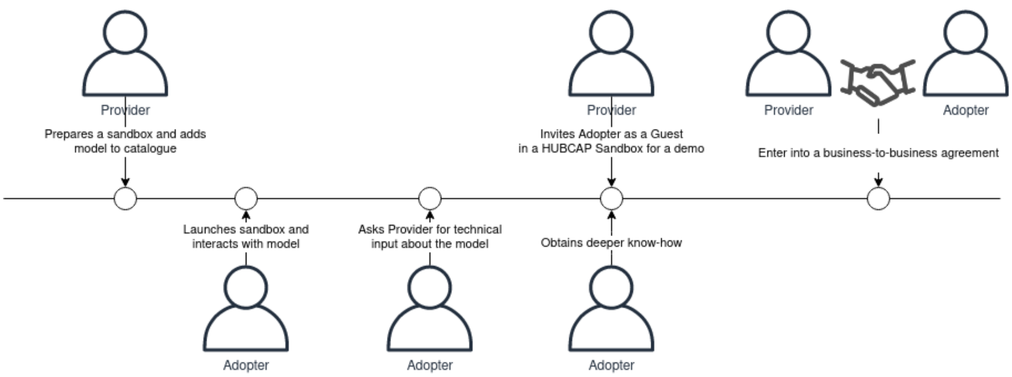

Fig. 4. Example timeline of MBD tools and models adoption and by manufacturing developers resourcing to the HUBCAP "test-before-invest" platform services.

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