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OMiLAB: A Smart Innovation Environment for Digital Engineers

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Abstract. This position paper introduces a Smart Innovation Environment for experimentation related to digital transformation projects, for the consolidation of a proposed "Digital Engineer" skill profile (with a business-oriented facet labelled as "Digital Innovator"). In the Internet of Things era, this profile implies the ability to perform both digital design and engineering activities, to semantically bridge multiple layers of abstraction and specificity – from business analysis down to cyber-physical engineering. In the paper's proposal, this integration is enabled by conceptual modelling methods and interoperable modelling tools, tailored to support the creation of Digital Twins for innovative digital business models. The architecture of the proposed environment is guided by a Design Research perspective – i.e., it is a treatment to an education "design problem" regarding the Digital Engineer skill profile in the IoT era. The proposed environment encompasses workspaces and toolkits are currently evaluated in "innovation corners" deployed across the OMiLAB ecosystem.

Keywords: OMiLAB · Digital Twin · Digital Engineer · Digital Innovator · Agile Modelling Method Engineering · Cyber-Physical systems

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1 Introduction

The growing popularity of the Digital Twin concept and the Internet of Things (IoT) paradigm reclaims new digitalisation skills. This paper proposes an updated vision on the *Digital Engineer* skill profile, with an alternative facet labelled as *Digital Innovator* - where a business analyst view gains priority. These profiles are still to be consolidated in higher education curricula, although they have been present for some time as organisational roles in digital transformation projects. The "Digital Engineer" term has been used as an educational profile since the late 90s [1] – however, in the IoT/Digital Twin era it must be updated, considering that interoperability and integration are rapidly evolving in scope and possibilities.

A challenge arising with this evolution is to set up adequate environments for developing and consolidating the Digital Engineer/Innovator skill profiles – i.e. to answer the questions: *what assets should be made available for an integrated experimentation or learning experience? how can the business view be integrated with conceptual and engineering views in a modular environment - deployed as either a research or didactic laboratory?* In response to this challenge, a Smart Innovation Environment is hereby presented. The environment is designed and tested in the collaboration network of the Open Models Laboratory (OMiLAB) [2] - a digital ecosystem previously presented as a socio-technical ecosystem with a focal point on conceptualisation processes in [3].

This paper isolates one key asset of the ecosystem – the **Smart Innovation Environment** for Digital Engineers, an orchestration of software/hardware resources and workspace configurations articulated in an experimental setup to serve either as a didactic or a research laboratory in OMiLAB "nodes" being set up in partner universities or companies. Specifically, the proposed environment incorporates workspaces for Digital Design Thinking and Digital Twin-based engineering, supported by appropriate integration platforms and interoperability facilitators, employing Conceptual Modelling methods to bridge the semantic gaps between Design Thinking results (of innovation workshops) and feasibility experiments with Digital Twins proofs-of-concept. Demonstration scenarios, reusable components and knowledge assets are being accumulated from the network effect of collaboration between organizations adopting the "OMiLAB node" status [2].

The work at hand is framed from a Design Research perspective [4], as a treatment to an education design problem – the development of the Digital Engineer skill profile. This framing will be outlined in Sect. 2. Section 3 will detail the pillars of the proposed environment and their key assets. Section 4 will comment on related works. The paper ends with a SWOT evaluation.

2 Problem Statement and Requirements

We start by formulating the motivating requirements for which the proposed innovation environment was developed. These requirements originate both in position statements regarding the Digital Engineer skill profile and in the human resource needs of recent research projects running in institutions involved in the OMiLAB collaboration network. According to [5], “the Digital Engineer will be a person with knowledge and skill in the use of engineering and digital technology to enable major process improvements and performance increases in both physical and business operations.” The role is intended to accelerate business insight “through more integrated asset management” within “highly instrumented facilities” (comprising enablers such as smart equipment, simulators etc.), with a profile that integrates “historically-disconnected skills”.

Additionally, the Conceptual Modelling education “design problem”, as framed in [6], inspired this work towards the aim of elevating the value of conceptual modelling from traditional use cases (software design, business process management) to a generalised value proposition, where modelling languages are “knowledge schemas” that can be tailored for any domain and depth of specificity. When this idea is coupled with interoperable modelling environments, it leads to a form of Digital Twin engineering that is *semantics-driven in the centre* (the so-called “next generation Digital Twin” [7]) and *computationally-intensive at the edge* (i.e. computationally-heavy tasks are delegated to cyber-physical systems and edge services). In Table 1 we aggregate a list of “environment requirements” for which this paper’s proposal was designed, together with brief suggestions about how they are addressed by the current environment architecture.

Table 1. Requirements for the Smart Innovation Environment

Requirement	How the Smart Innovation Environment addresses the requirement
The Modelling Method Agility requirement. There is a need for conceptual modelling methods that can be tailored for capturing multiple layers of abstraction, specificity and granularity – from high level business insights down to run-time constraints and properties	*Building on the tradition of multi-perspective enterprise modelling, the proposed Smart Innovation Environment employs a generic concept of “modelling method” introduced in* [8]*, whose building blocks can be tailored through metamodelling in order to achieve alignment with a targeted domain, specificity and granularity* *Integration and customisation of modelling languages are thus enabled, making them responsive to explicit “modelling method requirements” (as defined in* [9]*). An initial toolkit of agile modelling environments is provided*
The **Technology requirement.** There is a need for fast prototyping enablers – both for the agile modelling methods invoked in the previous point and for the cyber-physical counterparts of Digital Twins. Out-of-the box components must support evaluation and interoperability	*The proposed environment is built on three pillars – each with its own toolkits and interoperability features:* *(a) toolkit for Digital Design Thinking to support facilitation workshops and ideation at business scenario level;* *(b) toolkit for Digital Twin modelling and integration;* *(c) toolkit for engineering of Digital Twin-based cyber-physical demonstrators*

(*continued*)

Table 1. (*continued*)

Requirement	How the Smart Innovation Environment addresses the requirement
The **Openness requirement.** Open platforms and open interfaces are preferred in the choice of technology, to facilitate reuse prototypical building blocks and the accumulation of learned lessons	*The proposed environment includes a Web integration platform* [10] *and a set of out of the box adaptors/services to facilitate interoperability between modelling environments and external artefacts/systems* *A free metamodelling platform* [11] *is employed to ensure that all modelling tools are open to further adaptation or reuse. Openness is the fundamental motivator for the OMiLAB ecosystem and its collaboration network*
The **Digital Integration requirement**. Modelling environments must provide machine-readable semantic mediation from the business insights layer (where business model or product characteristics are co-created) down to the layer of cyber-physical demonstrators	*The modelling method engineering technology builds on the notion of* ***Smart Models*** *– i.e. Conceptual Models that have three key qualities:* *(a) they decompose a socio-technical system across multiple perspectives and levels of detail while preserving semantic links across those perspectives/levels;* *(b) they make diagrammatic content available to both humans and machines, covering a semantic spectrum ranging from highly abstract business ideas/service designs down to the level of executable artefacts;* *(c) they interact with other systems through a variety of connectivity options (pushing or querying model content)*
The **Knowledge Ecosystem requirement.** Co-creation requires shared knowledge assets to support knowledge transfer across adopters.	*The proposed environment benefits from being part of the OMiLAB digital ecosystem, whose on-line portal* [2] *and community events* [12] *facilitate both knowledge sharing and dissemination, while also enabling a social dimension, thus boosting its value as a collaboration network*

3 The Smart Innovation Environment of OMiLAB

Guided by the requirements summarized in Table 1, the proposed innovation environment was designed as a modular laboratory setup that can be easily packaged and deployed on an existing network infrastructure and a limited physical space of one typical lab room.

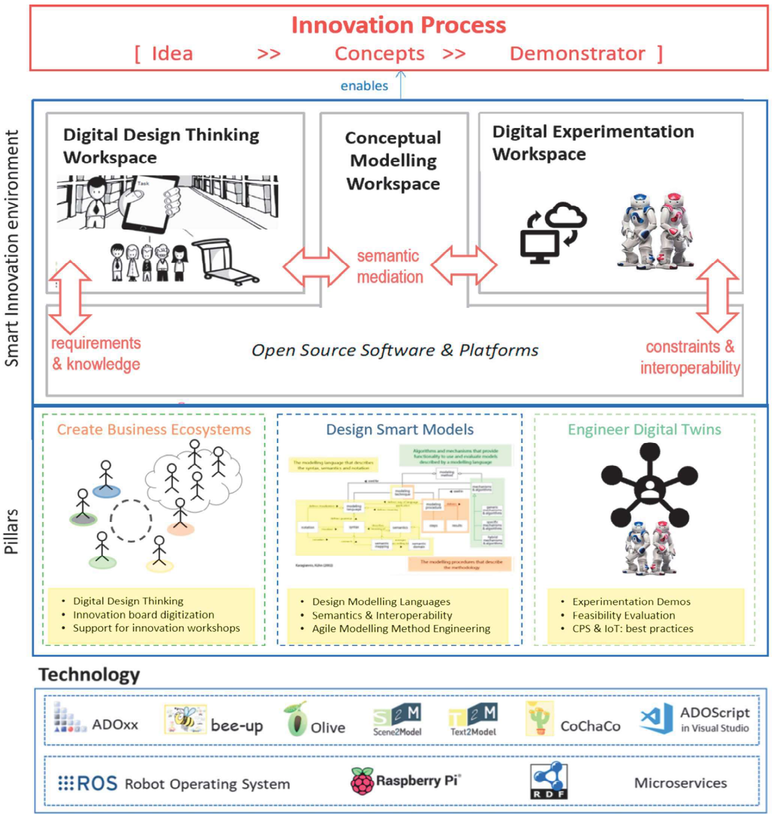

Fig. 1. Pillars, components and technologies of the Smart Innovation Environment

As illustrated in Fig. 1, it is conceptually built on three pillars – each instantiated in an operational workspace and reflecting one of three skill categories:

P1. Creation of Business Ecosystems – currently instantiated in a **Digital Design Thinking** workspace with a toolkit that supports the digitalisation of "innovation boards" that typically emerge during facilitation/innovation workshops.

P2. Smart Modelling – currently instantiated in a **Conceptual Modelling** workspace having at its core the BEE-UP [13, 14] modelling tool, which integrates and extends several established languages: UML, BPMN, EPC, ER, Petri Nets, DMN, Flowcharts. At the same time, to support the "smart model" qualities formulated in Table 1, it provides model interoperability (via HTTP requests or RDF model-to-semantic graph conversion [15]). In addition, the ADOxx metamodelling environment [11] enables further adaptation and extension of modelling tools for the targeted domain-specificity and purpose.

P3. Digital Twin Engineering – currently instantiated in a **Digital Experimentation** workspace that enables the development of cyber-physical demonstrators (Raspberry Pi-based, Robot OS-based) or virtual service demonstrators (e.g. process-aware apps, simulation reports).

In the following, a description of each workspace will be detailed together with the capabilities of their respective toolkits.

3.1 The Digital Design Thinking Workspace

This component supports problem-solving or product development teams that need to perform a participatory analysis of business requirements while co-creating innovative digital business models. The popular approach of Design Thinking [16] captures results in the form of innovation boards where goals, stakeholders, processes and product-service characteristics are pinned, grouped, colour-coded.

In more advanced approaches, graphic figurines can be employed for storyboarding – e.g. SAP Scenes [17]. The hereby proposed environment supports this practice with a toolkit for the digitisation of Design Thinking results – i.e. scene boards are captured by a Webcam and QR code software and transferred in the Scene2Model modelling environment [18, 19] where further annotation and machine-readable structuring can be performed. A mapping ontology maintains the correspondence between the SAP Scenes figurines (identified by QR codes) and concepts in the Scene2Model tool, thus enabling model queries and the semantic enrichment of storyboards with digital modelling means (Fig. 2).

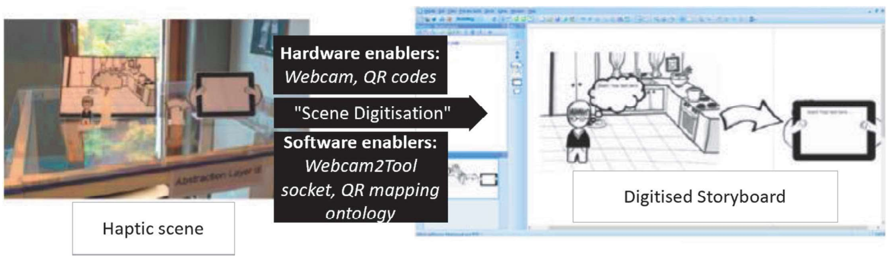

Fig. 2. The principle of Digital Design Thinking (adapted from [18])

3.2 The Conceptual Modelling Workspace

This is the central stage of the entire innovation environment, where co-created ideas are refined into "Smart Models" – i.e. conceptual models that are both human-readable and machine-readable, acting as a semantic and interactive representation of Digital Twins, further enabling model-driven engineering or interoperability with cyber-physical systems in the experimentation workspace. To enable full control on Digital Twin design and an open-endedness of the domain-specificity, the provided toolkit supports both modelling and metamodelling:

- the out-of-the-box BEE-UP tool offers a hybridisation of modelling languages for both engineering and business analysis needs: UML, BPMN, EPC, ER, Petri Nets, Flowcharts and DMN - semantic links across these languages enable a multi-layered description of a System of Systems with adequate granularity;
- the BEE-UP tool can be extended with richer semantics, additional model types or functionality that may be required for a selected domain/purpose; or, novel modelling methods may be developed from scratch with the help of the Agile Modelling Method Engineering methodology [20], applied in tandem with the ADOxx metamodelling platform [11] and the CoChaCo tool for managing the domain analysis and modelling method requirements [9].

In order to establish connectivity with run-time demonstrators, various interoperability channels are provided by both BEE-UP and ADOxx – e.g. HTTP requests can be triggered by model elements; model contents may be exported as RDF graphs to form a "knowledge base" for cyber-physical devices.

3.3 The Digital Experimentation Workspace

This is where software/hardware engineering takes places, taking input from the Smart Models designs and exploiting the model interoperability channels towards the realization of feasibility demonstrators. This streamlining is suggested by Fig. 3. Two categories of artefacts are typically developed:

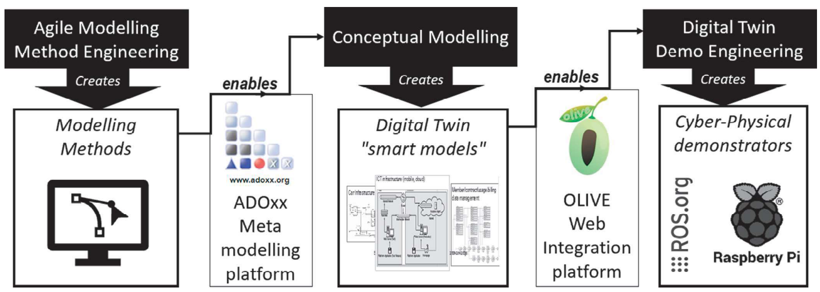

Fig. 3. Streamlined agile engineering activities for Digital Experimentation

- *IoT adaptors and micro-services*. The OLIVE Web integration platform [10] acts as a container for interoperability connectors with external services or physical objects, ensuring that communication between the modelling environment and cyber-physical demonstrators can be achieved (see exemplary service implementations in [21]);
- *Cyber-physical behaviour*. A starter package of robotic and IoT devices (Raspberry Pis or ROS-based), programmable through open interfaces, is provided for the prototyping of cyber-physical demonstrators. Once connected (through the Web integration platform) to the modelling environment, they gain various levels of "model-awareness" – from response-request communication to reasoning on model contents.

4 Related Works

Developing intellectual capital for Industry 4.0 is a major challenge, as digitalisation trends are changing skill profile requirements [22]. Innovation ecosystems can facilitate the creation and multiplication of digital engineering/innovation skills and setting up such environments has become a priority in higher education – see the "microfactory"-centered laboratory described in [23]. The hereby proposed innovation environment does not aim to define a full curriculum, but rather a modular, flexible package of training and experimentation resources that can be adopted for research and education based on innovation processes. Through its distinct but interoperating pillars and a Conceptual Modelling core, it was designed to support study programs in Business Informatics, Computer Science or Industrial Engineering, while encouraging hybrid programs for full benefits. Considerations on Digital Innovation curricula for Information Systems [24] have been taken into account, hence the Business Ecosystem Creation pillar was added as a business analyst-oriented perspective.

The current trends towards digital servitisation open value proposition towards the integration of value-added services associated to product lifecycles, leading to smart Product-Service-Systems (PSS) [25]. Digital engineers should be able to manage digitalisation challenges across multiple levels of smart PSS design – from innovation context analysis [26] to evaluation of alternatives [27].

The current proposal places an explicit focus on knowledge engineering as enabler for Digital Twin and IoT, towards a vision of Smart Systems where not only computational/algorithmic aspects are relevant, but also "by design" semantics that can be consulted at run-time by cyber-physical objects or their driving software agents. The enabled cognition has been detailed technically in works such as [28, 29] – the hereby proposed environment exploits in this sense the semantics component of diagrammatic modelling, which thus becomes a form of knowledge representation.

5 Concluding Evaluation

The paper presents the Smart Innovation Environment of OMiLAB – an operational modular artefact that can be deployed as a research or didactic installation to support Digital Transformation projects. Current deployments take the form of "innovation corners" set up in several universities – e.g., as environments for digital design skill development in the project DIGIFOF [30]. Based on this experience, we conclude with the following SWOT analysis:

- **Strengths:** The three pillars of the proposed environment contribute to developing a cross-disciplinary skill profile based on an "integrated separation" of concerns, covering Design Thinking, Conceptual Modelling and IoT engineering. Each pillar provides toolkits based on platforms with open interfaces. Modularity ensures that the different layers can also be employed independently for limited scopes. Agile Modelling Method Engineering ensures that the conceptualisation of Digital Twins can be tailored to any application domain or virtual enterprise;

- **Weaknesses:** The environment is continuously evolving as new requirements are identified; the current configuration is inherently limited and focused around a selected set of demonstration scenarios (e.g. currently not covering cybersecurity concerns) – however, the reliance on open platforms, open interfaces and general purpose cyber-physical platforms ensures an open-ended evolution;
- **Opportunities:** Both engineering schools and business schools can adopt the proposed environment as either a didactic or research laboratory. Hybrid study programs integrating "historically-disconnected skills" [5] can benefit from the modular yet interoperable proposed environment;
- **Threats:** The viability of the proposed environments depends on the uptake of the Digital Engineer/Innovator skill profiles updated for the IoT era. The Digital Twin notion hereby proposed has a semantic core and a computational flexible edge, which is not necessarily in line with traditional digital engineering tools, but reflects current knowledge-driven IoT deployment strategies.

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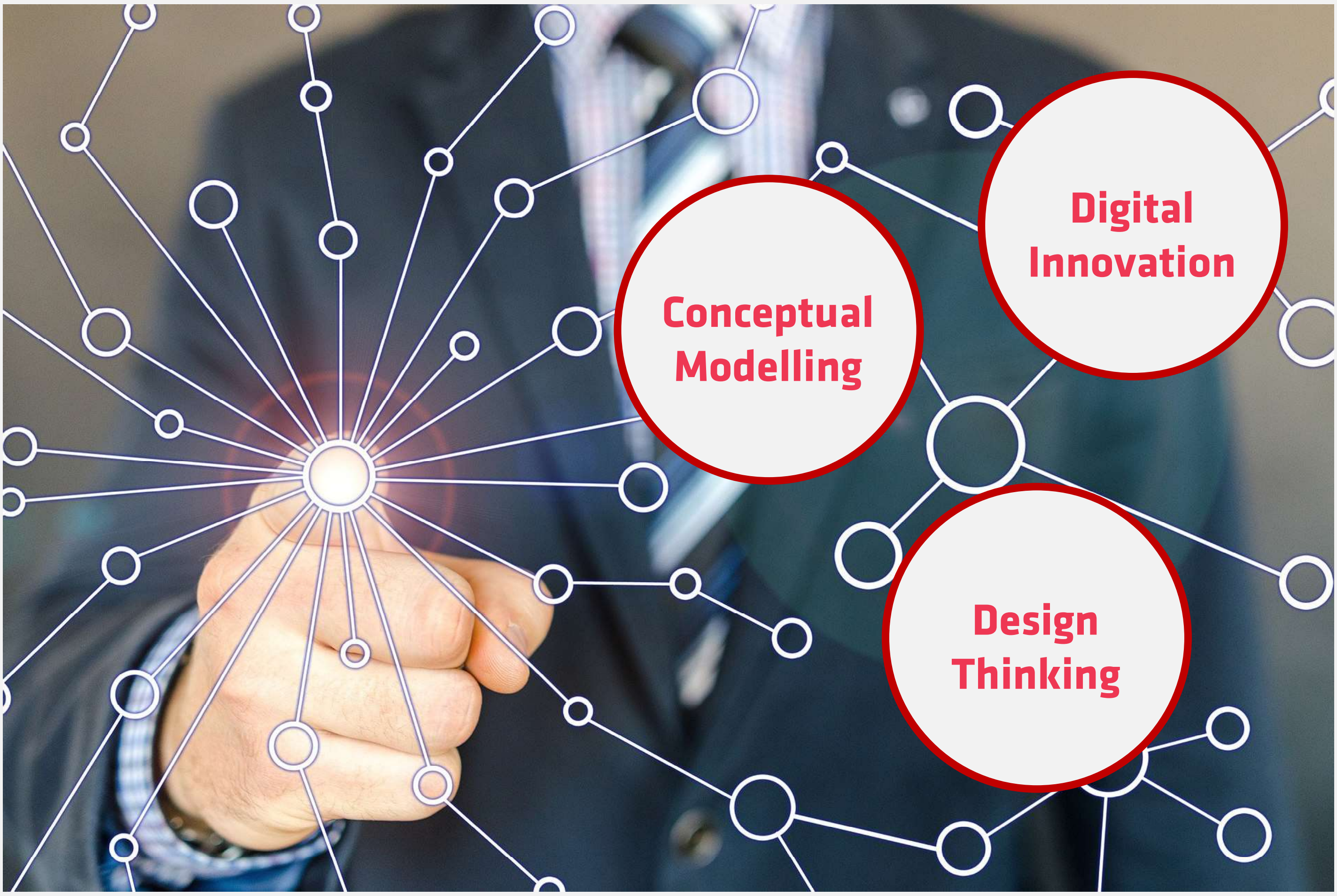

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