Bridging haptic Design Thinking and cyber-physical environments through Digital Twins using conceptual modeling

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Abstract

Considering the ongoing digital transformation, specialized environments that support the design, development, and evaluation of innovative business ideas are needed to meet the constantly changing requirements of various domains. Moreover, it is necessary to educate the upcoming generations in what we call a *Digital Leader* skill profile crucial for navigating this complex and interdisciplinary landscape. One approach to address these challenges is the Digital Innovation Environment supported by the OMiLAB community of practice, which advances the notion of bridging business ecosystems with cyber-physical environments through smart models. This contribution extends existing works on the utilization of the OMiLAB ecosystem by proposing an environment that leverages domain-specific conceptual models to establish interoperability between Digital Twins of Design Thinking and IoT environments. An educational setting is used to evaluate the feasibility of our proposed approach in addressing design issues related to the skill profile required for thriving in the digital transformation age.

Keywords

Digital Innovation Environment, Digital Leader, Haptic Design Thinking, Cyber-Physical Environment, Conceptual Modeling, Digital Twin, IoT, OMiLAB

1. Introduction

In recent years, the ongoing trend of digital transformation has led to the emergence of technology-based innovations in a variety of domains. Consequently, dedicated environments are necessary to support the rapidly changing requirements of designing, developing, and evaluating innovative business ideas that guide the digital transformation process. The *Open Model Initiative Laboratory* (OMiLAB) follows this notion by promoting a Digital Innovation Environment that is built on three core pillars: Pillar I focuses on creating innovative business ideas, and Pillar II employs agile conceptual models to serve as a bridge to Pillar III, which is about cyber-physical experimentation setups [1, 2, 3]. An instance of the Digital Innovation Environment materializes when this conceptual framework is applied to establish distinct physical

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laboratories with their own domain-specific focus. For example, instances of the environment have been employed in the literature to address educational design issues related to the skill profile that is needed to prevail in the digital transformation age [4, 5, 6].

Within this contribution, we build upon existing works that employ the Digital Innovation Environment by proposing a specialized instance of it in which domain-specific conceptual models are utilized to bridge Digital Twins of innovative business ideas and cyber-physical environments. Specifically, haptic Design Thinking workshops [7], domain-specific conceptual modeling methods [8], and cyber-physical IoT environments [9] are utilized, with each component representing one of the fundamental pillars of the Digital Innovation Environment. Furthermore, we evaluated the proposed instance within an educational setting to assess its feasibility in addressing the mentioned design issues discussed in the literature.

The remainder of the contribution is structured as follows: Section 2 identifies the design problem and derives corresponding requirements. Subsequently, Section 3 discusses relevant concepts and tools, encompassing the OMiLAB Digital Innovation Environment, varying Digital Twin interpretations, and relevant open-source software. Section 4 introduces a new instantiation of the OMiLAB innovation environment, which is applied and evaluated in the educational context within Section 5. Finally, the results of this contribution are summarized in Section 6.

2. Problem Statement and Requirements

The digital transformation age requires a certain skill profile to navigate the highly complex and interdisciplinary environments related to it. A corresponding educational profile of a so-called *Digital Engineer* has already been proposed decades ago [10]. Nevertheless, it has since been noted that such profiles need to be updated in light of the ongoing digital transformation and have yet failed to be commonly integrated into higher education curricula [1, 6]. The work at hand aims to address this and other interrelated challenges discussed in the literature, encompassing the development of an updated Digital Engineer skill profile [1] which can serve as treatment for the design problem in conceptual modeling education [4, 5, 6].

The first step in updating the profile of a Digital Engineer is to consider a wider skill set that is required in digital transformation projects. On this notion, previous works have emphasized the necessity that Digital Engineers also need to possess a business-oriented facet, which they labeled *Digital Innovator* [1, 2]. In a more extensive consideration, three historically separate skill sets are attributed to the Digital Engineer/Innovator: (i) business analyst with an innovative business view, (ii) knowledge engineer with the ability to design Digital Twins, and (iii) prototype developer capable of engineering cyber-physical environments [5]. The consolidation of these three roles is subsequently labeled as *Digital Leader*, which forms the basis for the skill-related requirements documented in Table 1 and the innovation environment presented in Section 4.

Following these insights and related works, we frame the research at hand as a Design Science artifact [11] that aims at contributing to the efforts of establishing an updated Digital Engineer skill profile to be used in education. A fundamental challenge going along with this research goal is the availability of adequate environments for designing, developing, and evaluating the respective skills. Subsequently, we elaborate in more detail on how the mentioned Digital Innovation Environment of OMiLAB can be utilized to address this challenge adequately. We conclude the section by highlighting skill-related requirements that correspond to the Digital Leader profile and link them to environment-related requirements (cf. Table 1) that have already been addressed through the utilization of the OMiLAB Digital Innovation Environment [1, 5].

Table 1
Requirements for establishing and updated Digital Leader skill profile

Requirement	How the requirement is addressed
Environment-related (based on [1, 5])	
Technology requirement Availability of tool kits that enable fast prototyping and interoperability across all layers concerning a Digital Leader.	The three skill sets we have attributed to the Digital Leader profile are each supported with out-of-the-box tool kits, as shown in Section 3.3 and also in [1, 5].
Digital Integration requirement Enabling interoperability between layers through smart models designed with agile modeling methods.	Smart models designed in a supportive modeling environment form the bridge that enables interaction between systems used on different layers while encoding semantics as diagrammatic models that are both human- and machine-interpretable.
Modeling Method Agility requirement Tailoring of bridging modeling methods to the desired level of abstraction, domain, and purpose.	The generic modeling method framework [12] is utilized in combination with the agile modeling method engineering (AMME) life cycle [13] to enable adaption and customization of modeling methods in line with changing requirements.
Openness requirement Choice of tools and technologies should satisfy the openness principle to ensure reusability and transparency.	The openness notion applies to the software employed in this contribution (cf. Section 3.3). In addition, the ADOxx metamodeling platform [14] used to develop modeling methods is free, ensuring adaption and reuse of created artifacts.
Skill-related (inspired by [5])	
Business Model Innovation requirement Digital Leaders must be willing to challenge existing concepts to innovate and realize novel business models.	Haptic Design Thinking workshops are used to foster the creation of innovative solutions in interdisciplinary teams that are supported by the *Technology requirement* and the *Modeling Method Agility requirement*. More details are provided in Section 4.1.
Model-based Bridging requirement Digital Leaders must leverage smart models to bridge innovative business ideas with cyber-physical environments.	Conceptual models are utilized to bridge business innovations with cyber-physical environments. The bridging is supported by the *Digital Integration requirement* and the *Technology requirement*. More details are provided in Section 4.2.
CPS Realization requirement Digital Leaders must be able to realize cyber-physical experimentation environments used for evaluation.	Cyber-physical environments are set up based on the Design Thinking workshop results. Using IoT devices (e.g., sensors, actuators, microcontrollers), the feasibility of he innovative business models can be evaluated. More details are provided in Section 4.3.

3. Theoretical Foundations and Tools

3.1. OMiLAB Digital Innovation Environment

The OMiLAB embodies a global community of practice that actively supports the vision of utilizing open conceptual modeling artifacts as diagrammatic Digital Twins to provide innovative solutions for the challenges of the ongoing digital transformation process. These efforts manifest

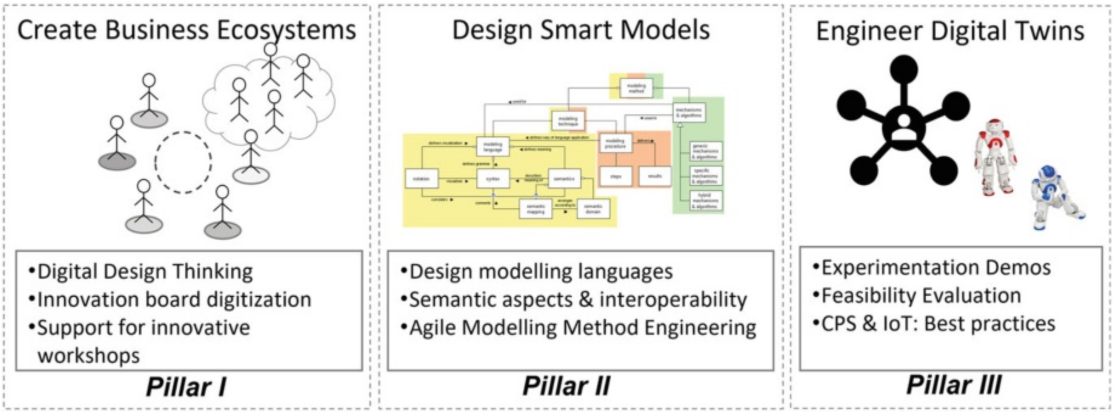

Figure 1: OMiLAB Digital Innovation Environment [2]

in a global network of physical laboratories that are established as instances of the Digital Innovation Environment. This means that each laboratory adheres to the same principles captured by the fundamental pillars described in the following, while the implementation of each pillar may differ according to the domain-specific focus of the respective laboratory instance [2]. In this context, smart models form an invariant that is employed by every instance to bridge value-driven business views and technology-driven engineering views [5]. To enable the design of such bridging models, dedicated modeling languages are utilized, which have manifested in a variety of modeling tools developed by the OMiLAB community[1].

Due to the fact that the Digital Innovation Environment has been discussed and applied in great detail in the existing literature [1, 2, 3, 5, 15], we decide to focus on its core aspects represented by the three fundamental pillars illustrated in Figure 1.

The **first pillar** is labeled as the creation pillar, which addresses the increasing need for innovative business ecosystems in the face of digital transformation. To support this need, co-creation, and problem-solving workshops based on Design Thinking are utilized to empower the Digital Innovator role (cf. Section 2) to create innovative business models [1]. These Design Thinking workshops can be tailored for every Digital Innovation Environment instance, depending on the respective domain and purpose. The resulting manifestation of this pillar within the context of this contribution is presented in Section 4.1.

The **second pillar** focuses on the design of smart models, corresponding to the elaborations on the *Digital Integration requirement* and the *Modeling-based Bridging requirement* introduced in Section 2. The resulting activities are guided by the open metamodeling platform ADOxx [14] and the AMME life cycle [13], which enable continuous adaptions and reuse of designed modeling languages to meet changing requirements [2]. The variety of instances developed in this way is captured by modeling tools of the OMiLAB community, as has been mentioned above. Further explanations on how this pillar enables the bridging between pillars one and three within this contribution follow in Section 4.2.

The **third pillar** is concerned with the engineering of Digital Twins, a widely used term that

[1]https://austria.omilab.org/psm/exploreprojects

is delimited in the next section. Within the Digital Innovation Environment, this pillar supports the setup and configuration of experimental proofs-of-concept using suitable technologies. The resulting cyber-physical environments can interact with smart models [3] and, moreover, serve as feasibility evaluations [1, 2]. Within existing implementations, IoT devices, humanoid robots, robotic cars, and drones have been used to set up such experimental proofs-of-concept [3, 15] The instantiation of the third pillar in the context of the *Smart Innovation Environment for Digital Engineers* proposed in this contribution is discussed in Section 4.3.

3.2. Digital Twin Interpretation

The concept of *Digital Twin* has been subject to significant debate within the scientific literature, with diverse definitions and a lack of consensus on its core characteristics. Some authors clearly differentiate in this regard between digital and physical twins, and the auxiliary components needed to enable mutual information transfer between them [16, 17]. On the same notion, Digital Twins have been categorized based on the existence of their respective counterparts [18]. To that effect, they can manifest as a prototype with no physical counterpart used for simulations and testing in early development stages. In contrast, Digital Twins can also serve as real-time models of established instances that facilitate controlling and analyzing the physical twin counterparts [9, 19]. It has been noted that the OMiLAB environment supports all of these approaches as part of the third fundamental pillar (Engineer Digital Twins) [2].

Within this contribution, we follow the semantic-driven notion of Digital Twin presented in [1, 5], according to which interrelated models that are both human- and machine-readable can be utilized to form coherent Digital Twin representations. As a result, we consider digital representations of Design Thinking environments and cyber-physical environments just as much as Digital Twins as the smart models employed to bridge these two (cf. *Digital Integration requirement* and *Model-based Bridging requirement* in Section 2).

3.3. Open Source Software Support: Scene2Model and openHAB

In the following, we introduce selected open-source software based on its relevance within the *Smart Innovation Environment for Digital Leaders* (cf. Section 4).

Scene2Model Scene2Model is an ADOxx-based conceptual modeling environment designed to facilitate the integration of haptic Design Thinking workshops with computer-processable representation in the form of conceptual models [7, 20]. The term *haptic* refers to Design Thinking methods that employ haptic materials, such as tangible artifacts in the form of sticky notes, paper figures, and many others. These materials offer a physical point of contact for participants during workshops, thereby amplifying the efficacy of exploring and designing innovative ideas. Consequently, physical workshops are commonly used in Design Thinking [21] as they provide valuable support for co-creation among participants by enabling the utilization of tangible artifacts representing their ideas. For the creation of innovative ideas within the workshops, experts from diverse domains must thus be able to externalize their knowledge and engage in effective communication for collaborative innovation design [22]. In this context, Scene2Model supports workshops by offering a modeling environment that captures the tangible artifacts (based on SAP Scenes[2]) as a digital model [7, 20]. Further assistance for participants is provided through Scene2Model's automated transformation of tangible artifacts into digital models that can be enhanced with additional information. More specifically, each paper figure is converted into an adaptable modeling object, thereby providing a flexible and efficient approach to conceptual modeling within Design Thinking workshops [23].

OpenHAB Open Home Automation Bus (OpenHAB) is a Java-based open-source platform used to manage IoT devices in the context of home automation. The platform enables users to create a digital representation of physical IoT devices, which can serve as a controller and state monitor for the corresponding physical devices [17]. Within the context of *OpenHAB*, these digital representations are referred to as "items". Establishing connectivity between the IoT platform and the respective devices is enabled through channels that employ diverse protocols such as HTTP and MQTT. These channels ensure a continuous link between the platform and the connected devices, thereby facilitating seamless data exchange. Once channels are established, *OpenHAB* offers robust automation capabilities through the use of rules and events, allowing users to define specific conditions that trigger actions within the IoT environment. Moreover, *OpenHAB* provides a Representational State Transfer (REST) API, enabling interface-independent adaptations of the environment. This capability allows for seamless integration and manipulation of the physical IoT environment across diverse systems [24].

4. Smart Innovation Environment for Digital Leaders

The core contribution of this work is the proposal of a domain-agnostic instance of the OMiLAB Digital Innovation Environment that integrates the previously discussed open-source software with a focus on addressing the interrelated design problems in regard to the Digital Leader skill profile established in Section 2. In accordance with this skill profile, we coin the proposed instance as *Smart Innovation Environment for Digital Leaders*. The environment operates on three distinct layers, which correspond to the three fundamental pillars of the OMiLAB Digital Innovation Environment (cf. Section 3.1). Additionally, we distinguish between a physical and digital space which is based on the differentiation between Physical and Digital Twins discussed in Section 3.2. The resulting three-layered architecture is displayed in Figure 2, with elaborations on each of the layers being presented subsequently.

4.1. Design Thinking Layer

The innovation of business models forms one of the skill-related requirements introduced in Section 2, which is supported by the creation pillar of the OMiLAB Digital Innovation Environment. For this purpose, haptic Design Thinking workshops are utilized to foster communication and co-creation among interdisciplinary workshop participants who have to decompose scenarios into their essential components. To support this process, the OMiLAB community offers an out-of-the-box tool to automatically transform haptic scenes created during the workshops into *Digital Twins of the Haptic Design Thinking Environment*, namely Scene2Model (cf. Section 3.3).

[2] https://apphaus.sap.com/resource/scenes

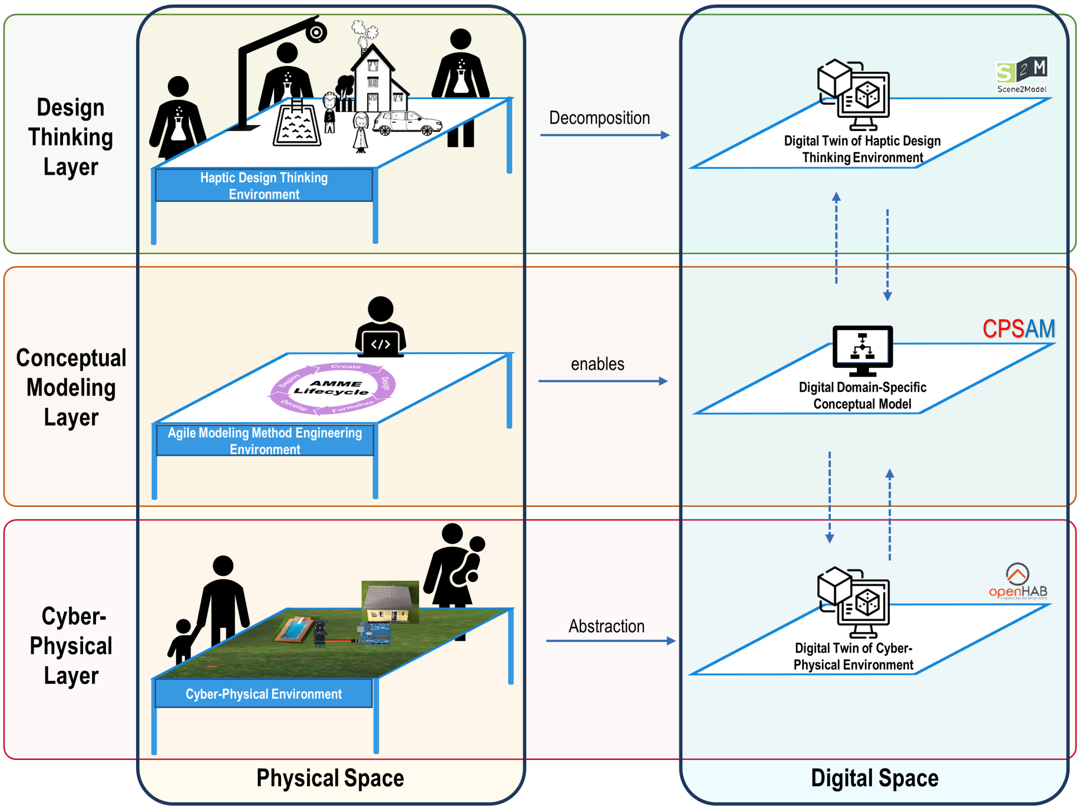

Figure 2: Smart Innovation Environment for Digital Leaders (using Scene2Model, CPSAM, OpenHAB)

The combination of physical Design Thinking workshops with dedicated technology support has proven to be a promising approach within the OMiLAB ecosystem [1, 2, 3, 5, 7, 15, 20].

Within the context of the *Design Thinking layer*, we apply the semantic-driven notion of a Digital Twin described in Section 3.2. Digital representations of the physical artifacts created during the workshops thus form Digital Twins that are more than mere digital copies of the physical artifacts, as they contain implicit knowledge assigned to the interpretation of tangible artifacts that can be enhanced with further semantics to support the aggregation of captured knowledge. Additionally, the digital models not only allow for capturing knowledge but also to analyze and process it. In this contribution, the knowledge gathered from the workshops can be processed in a manner that enables its utilization as input for the bridging process between the haptic Design Thinking environment and the cyber-physical environment. This feasibility is achieved as the models incorporate paper figures that not only serve as instances but also have assigned classes, offering essential context information that facilitates the processing of models.

In summary, haptic Design Thinking workshops are employed within the *Design Thinking layer* to foster novel business ideas, which are then decomposed into Digital Twins represented as conceptual models that can be adapted and refined using the Scene2Model tool.

4.2. Conceptual Modeling Layer

The *Conceptual Modeling layer* forms the essential bridge between the *Design Thinking layer* and the *Cyber-Physical layer*, thereby corresponding to the *Model-Based Bridging requirement* of the updated Digital Leader skill profile (cf. Table 1). Just as the other two layers of our innovation environment, the bridging layer is supported by dedicated technology, as specified by the *Technology requirement*. The respective tool utilized within the *Conceptual Modeling layer* is named Cyber-Physical System Abstraction Model (CPSAM), which is not listed under the selected open-source software, as it is currently in an iterative prototype phase. Its design is based on ADOxx [14], guided by the AMME lifecycle [13] , and enabled by a method engineer through the creation of the modeling method. These elements supporting the *Conceptual Modeling layer* constitute the core aspects of the second pillar of the OMiLAB Digital Innovation Environment and also form the basis for the co-creation of model-value [15].

The CPSAM method employed within this contribution is designed to bridge the Digital Twin of the haptic Design Thinking environment with the Digital Twin of the cyber-physical environment. The focus of the bridging lays on retrieving necessary IoT devices as well as capability requirements from the scenario defined during the Design Thinking workshops and mapping them to rules, which can be directly executed within the cyber-physical environment by interacting with the Digital Twin connected to it. To achieve this bridging, an interoperability algorithm is established between the Digital Twin of the Design Thinking workshop and the conceptual modeling method that enables the import of requirements. In addition, the REST API provided by the IoT platform employed on the third layer is utilized to import the abstracted IoT devices, established rules, and events from the Digital Twin of the cyber-physical environment into the same model. The mapping process is then carried out manually by the modeler, who can subsequently deploy the enhanced requirements back into the IoT environment.

In essence, conceptual models form the bridge within the proposed *Smart Innovation Environment for Digital Leaders*. In this context, the CPSAM method facilitates the retrieval and mapping of IoT devices and capabilities from digital scenes to rules that can be executed within cyber-physical environments, enabling seamless interaction between the layers.

4.3. Cyber-Physical Layer

The *Cyber-Physical layer* plays a critical role in the testing and evaluation of scenarios created in the first layer, as emphasized within the *CPS Realization requirement* (cf. Table 1). This aspect of our architecture is supported by the third pillar of the OMiLAB Digital Innovation Environment through experimental setups in physical laboratories using IoT devices, although other contributions also employed different technologies on this proof-of-concept layer, like cyber-physical systems of robots [3] or process execution environments [15]. Moreover, the *Cyber-Physical layer* contains both the physical experimentation environment as well as a Digital Twin of the IoT devices represented in that environment. Such Digital Twins are created by abstracting the capabilities as well as data exchanges of the physical devices and can thus serve as both controller and state monitor for the corresponding physical device, which is in line with the conceptual framework of Digital Twin presented in [17].

Within the proposed instance of the *Cyber-Physical layer*, this abstraction is achieved using an open-source Iot platform called OpenHAB (cf. Section 3.3), providing an interface to external systems. By creating Digital Twins of the physical experimentation environment, a seamless data flow between the *Cyber-Physical layer* and the *Conceptual Modeling layer* is established, as elaborated in the previous section. The resulting connection enables the deployment of scenarios into a physical proof-of-concept environment using rules and events, which are created in the form of conceptual models within the context of the proposed innovation environment.

In conclusion, the *Cyber-Physical layer* serves as an environment in which innovative solutions originating from the *Design Thinking layer* are first realized in an experimental setup using IoT devices. Afterward, functionalities can be designed as conceptual models and automatically realized in the physical environment, thereby allowing for comprehensive testing and evaluation.

5. Artifact Application and Evaluation in Education

To evaluate the proposed *Smart Innovation Environment for Digital Leaders*, we describe a concrete application case situated within the education domain.

5.1. Application Case in Education

The proposed innovation environment has been applied during three separate Digital Leader sessions of the NEMO Summerschool Series[3] 2023, which provides interested students with accessible education on "the importance of conceptual modelling, semantics, and technologies for digital ecosystems." [2] Each session lasted one hour and was conducted in three separate groups consisting of twelve participants with an allocated advisor who offered assistance if needed. In advance, students took part in a one-hour demonstration lecture that introduced them to the underlying environment. The process of each session is explained below, with their design conforming to the three layers of the proposed innovation environment, therefore consisting of (i) a haptic Design Thinking workshop to innovate business models, (ii) a hands-on exercise to engineer an IoT environment (using provided sensors, actuators, microcontrollers), and (iii) a conclusive realization of cyber-physical functionalities through conceptual models:

i The **haptic Design Thinking workshop to innovate business models** was conducted to foster innovative scenarios within assigned domains. As input, the technical infrastructure for the Scene2Model tool (cf. section 3.3) and a set of 35 paper figures fitting to their domain was provided. Students then had to decide on their concrete scenario and define it using Scene2Model in a guided workshop, where individual figures could be added if necessary. The role of the advisor was to operate the software and provide directions if the students got stuck or lost in details.

ii The **exercise to engineer an IoT environment** entailed that students had to establish their own IoT-based experimentation environment by abstracting from the previously designed scenario. To enable this setup, an Arduino with corresponding software, a pre-defined set of sensors and actuators, and a Raspberry Pi with a prepared OpenHAB instance (see section 3.3) were provided. Using these supplies and a wiring diagram, the

[3]https://nemo.omilab.org/

respective sensors and actuators had to be connected to the Arduino in the next step before establishing communication between the openHAB instance and the connected IoT devices. Finally, the students had to define how they want to represent their scenario from the first session within the experiment environment.

iii The session on the **realization of cyber-physical functionalities through conceptual models** was about bridging the scenario from the first session with the experimentation environment from the second. In this context, students needed to model the capabilities necessary for the respective scenario using the CPSAM modeling tool. Sensors and actuators defined in the previous session were automatically imported into models, which could then be mapped to self-defined rules using the corresponding visual representations. Once modeled, the cyber-physical functionality was automatically deployed to the connected openHAB instance through integrated tool functionalities. Finally, sensors in the environment were used to test the defined cyber-physical functionalities.

5.2. Empirical Evaluation

For the purpose of evaluating the Digital Leader sessions that were based on the innovation environment presented in Section 4, an empirical assessment was conducted to document their experiences after the students had presented their final results in a separate fourth session. In doing so, we followed the assessment design presented in [25] using a survey. Overall, 36 students participated in the sessions, of which 34 completed the assessment.

Survey Design The design of the survey was based on the three skill-related requirements we aimed to address by using the proposed innovation environment as the fundamental structure of the Digital Leader sessions while also considering the environment-related requirements to a certain extent. The resulting structure of the conducted survey is as follows:

1. Personal information (age, academic field, background)
2. Prior knowledge & current understanding of the innovation environment
3. Experience with (a) Design Thinking, (b) Cyber-Physical, (c) Conceptual Modeling layer
4. Additional statements

Results *Personal information:* The age distribution of respondents revealed that the majority fell within the 25-34 years age group (61.74%)[4], followed by 18-24 years old (23.52%), 35-44 years old (8.82%), and above 45 years old (5.88%). Regarding the academic background, the participants covered a diverse range of fields, with Business Informatics (26.46%), Computer Science (23.52%), and Information Systems (14.7%) being the most prevalent. Furthermore, multiple Engineering disciplines (Electrical 8.82%; Software 5.88%; Requirement 2.94%) and business-related fields, like Business Process Management, Business Intelligence, Enterprise Architecture, Information Management, and Economics (14.7% combined), were mentioned individually, just as Cultural Heritage (2.94%). As for occupation, PhD students are the most represented group (35.28%), followed by industry-related occupations (29.4%), teaching or research assistants (17.64%), and Masters or Bachelors students (11.76%). Two participants stated no occupation (5.88%).

[4]For simplification, the weight for each provided answer was rounded to 2.94% within the Results section.

Prior knowledge & current understanding of the innovation environment: Participants' prior knowledge and current understanding of each layer in the innovation environment were assessed through ratings on a scale from 1 (Not at all) to 5 (Very much). Design Thinking and conceptual modeling received higher average scores (Mean: 3.23) than setting up cyber-physical environments (Mean: 2.59). Subsequently, participants were presented with the *Smart Innovation Environment for Digital Leaders* (cf. Figure 2) as a reminder and asked to rate their understanding on the same scale. The average score indicated a favorable perception (Mean: 3.71), but written responses revealed some variability, with not all those providing a score of 5 understanding it well, and some who expressed a score of 3 demonstrating good comprehension.

Experience with Design Thinking layer: Regarding the experience with the Design Thinking layer, participants rated three statements on a scale from 1 (Not at all) to 5 (Very much). They found the haptic Design Thinking environment beneficial for generating innovative scenarios (Mean: 4) and perceived the tangible paper figure as fostering creativity and cooperation (Mean: 4.06). Lastly, the Scene2Model tool was seen positively for supporting the digitalization of the created scenarios in the haptic Design Thinking environment (Mean: 3.79).

Experience with Cyber-Physical layer: Participants were asked to rate two statements related to the cyber-physical layer on the same scale. Participants found establishing a real-world proof-of-concept challenging, although to a lesser extent compared to previous scores (Mean: 3.62). Additionally, they generally agreed that setting up a cyber-physical environment helped them understand relevant technical capabilities for their scenarios (Mean: 3.88).

Experience with Conceptual Modeling layer: In the section about the experience with the conceptual modeling layer, participants rated three statements. They agreed in regard to the helpfulness of the conceptual modeling layer in understanding the relationships between the three layers (Mean: 3.76) and the value of using conceptual models as a bridging component (Mean: 3.91). However, the use of the CPSAM method for easing the definition and deployment of required capabilities received one of the lowest scores in the positive range (Mean: 3.38).

Lessons Learned *Additional statements:* The learned lessons are based on the answers provided under the open questions of the additional statements section. Here, students were asked to share what they liked and disliked about the Digital Leader sessions and if they would recommend the approach to their peers. Table 2 displays the respective results in the form of the most-mentioned aspects and corresponding distributions, which are calculated including six participants that didn't provide any input to these questions.

In summary, the practical and hands-on activities within the sessions received the most appreciation (29.4%). Moreover, the collaborative and interdisciplinary environment was perceived positive, alongside the equally favored structure of the three-layered approach (17.64%). Time constraints and pressure emerged as the primary challenge, with nearly a quarter of participants expressing this concern (23.52%). The dynamics of group size and composition were also noted as areas of consideration (17.64%), with some responses even mentioning both concerns together (8.82%). Encouragingly, most of the participants stated their willingness to recommend the approach adopted in the Digital Leader sessions to their peers (82.36%), while nearly a fifth held a divergent viewpoint (17.64%). These findings highlight the multifaceted impact of the Digital Leader sessions, offering a comprehensive view of their effectiveness and areas for refinement.

Table 2
Overview of lessons learned from the conducted Digital Leader sessions

Question	Most Mentioned Aspects
1. What did you like about the Digital Leader sessions?	Hands-on/practical activities (29.4%) Collaborative/interdisciplinary environment (17.64%) Three-layered approach (17.64%)
2. What did you not like about the Digital Leader sessions?	Time constraints/pressure (23.52%) Group size/compostion (17.64%) Time constraint & group size (8.82%)
3. Would you recommend the approach used during the Digital Leader sessions to your peers?	Yes: 28 (82.35%) No: 6 (17.65%)

In the face of the problem statement presented in Section 2, these insights can be utilized in the future to advance the proposed skill profile of a Digital Leader in education.

6. Conclusion

In this contribution, existing design problems regarding the development of an updated skill profile are addressed, which is necessary to navigate the complex environments of the digital transformation age and can ultimately serve as treatment for conceptual modeling issues in education. We coined our proposal of a corresponding skill profile *Digital Leader*, combining the roles of a Digital Innovator, Digital Engineer, and Knowledge Engineer. Building upon these facets, we present a *Smart Innovation Environment for Digital Leaders* structured within the OMiLAB ecosystem, which caters to the requirements discussed in this work. The resulting architecture consists of three layers (Design Thinking, Conceptual Modeling, and Cyber-Physical), each representing a crucial component of the Digital Leader skill set. In this environment, innovative business ideas generated during haptic Design Thinking workshops are transformed into Digital Twins on the first layer. These Digital Twins serve as the foundation for setting up experimental IoT environments on the third layer. In the middle layer, smart conceptual models act as a vital bridging element, connecting the first and third layers. The proposed environment was tested and evaluated in an educational setting to further advance the Digital Leader notion by making key insights and lessons learned available to the community.

By incorporating the *Smart Innovation Environment for Digital Leaders* into curriculum development, educational institutions can nurture future leaders capable of thriving in the digital transformation age. Moreover, the insights gained from the educational evaluation setting require deeper analysis and will inform ongoing refinements to the Digital Leader skill profile and the Smart Innovation Environment. Finally, future works may explore the extension of this integrated approach to various domains through collaborative efforts among academia and industry within the OMiLAB ecosystem to shape the future of digital leadership.

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