PNEUMATICS LABORATORY INTERACTIVE EDUCATIONAL EXPERIENCE DEVELOPMENT

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ABSTRACT

In the recent past, gamification has been promptly developing as well as actively applied in the educational sector. Nowadays, it figures prominently on account of making the learning process more engaging and motivating which leads to enhancement of the quality of gained knowledge. The preservation of the existing level of education or, moreover, its strengthening. Additionally, these tools enhance and support the contactless learning methods that emerged during the COVID-19 pandemic. The redeployment of laboratory works into the gamification experience format allows students to perform tasks without the necessity to attend the designated laboratory room as well as reduce its utilization. The main objectives of the gamification experience are the establishment and contribution of the virtual tool to the Educational Game Project that is being developed by the Virtual and Augmented Reality laboratory at Tallinn University of Technology. The laboratory of the "Hydraulics and Pneumatics" course is utilized in order to prepare educational videos. The primary software tool implemented in the project is the Unity game engine due to its broad functionality while collaborating with 2D and 3D environments. Once a student has completed the designated task, they gain access to the next laboratory work as well as can revise their previous assignments. Current work presents the process of digitalization of the lab with the analysis of students' feedback on comparison between in-class and remote learning in the same lab.

KEYWORDS

Gamification experience, Pneumatics, Remote laboratory, Interactions, Standards 6, 8, 9, 10, 11, 12

1. INTRODUCTION

In recent years, gamification has been rapidly developing and applied in the educational process. The term "gamification" is generally used to denote the application of game mechanisms in non-gaming environments to enhance the processes enacted and the experience of those involved. The term has become a catchword throughout the fields of education and training, thanks to its perceived potential to make learning more motivating and engaging (Caponetto, Earp & Ott, 2014), especially among younger generations. While commonly found in marketing strategies, it is now being implemented in many educational programs as well, helping educators find the balance between achieving their objectives and catering to evolving student needs (Mertala, 2019). As a result, the elements of novelty in performing learning tasks are among the most critical factors for this development (Shevtshenko, et al, 2017).

The role of gamification in engineering education has become increasingly central and prominent with growing adoption in different areas of education and particularly software and computer engineering (M. Milosz & E. Milosz, 2020). Gamification tools and methods have beneficial effects on how students learn and process information. Interactive games in education stimulate interest and increase critical thinking, boost problem-solving competencies (Anil Yasin & Abbas, 2021), and are proven to increment academic performance, collaboration, and teamwork skills (Díaz-Ramírez, 2020). The development of new teaching methods in engineering is strictly bound to the development of new technologies in the field of industry. The ongoing and forthcoming transformations in the manufacturing field and Industry 5.0 (I5.0) are forcing education to adapt to new requirements, competencies, and skill sets (Broo, Kaynak & Sait, 2022). Multidisciplinary project developments, human-centric production lines, data-driven intelligent systems, and highly sophisticated collaborative work processes, in which humans and machines mutually learn from each other, are pushing higher education to provide adequate minds and skillsets to future engineers and technicians. In this regard, gamification and advanced collaborative interfaces, such as the one provided by augmented and virtual reality (Lampropoulos, et al, 2022), can be beneficial and preparatory to those future challenges. The examples in the literature are, of course, diverse but show a lively scenario of varied applications with mobile-based augmented reality interactive tools (Criollo, et al, 2021), the implementation of leaderboards (Ortiz-Rojas, Chiluiza & Valcke, 2019), the application of immersive Virtual Reality (VR) in automotive design teaching (Cordero-Guridi, et al, 2022), or the development of a dedicated toolbox for the analysis, virtualization, interaction, and exploitation of virtual factories and production lines for education though web tools (Mahmood, et al, 2021).

The main objectives of the presented application are the creation and implementation of a virtual tool into the Educational Game Project to digitalize methods of learning Pneumatics and Hydraulics. The project is being developed by the Virtual and Augmented Reality laboratory at Tallinn University of Technology. The gamification experience is conducted in a desktop-based 2D environment and the design of the gamification experience is inclusive of the "Main Menu" and 9 laboratory works on Pneumatics and 4 laboratory works on Electro-Pneumatics with corresponding educational videos. The task of each laboratory work is to compose a schematic, namely, the selection of the necessary components and the construction of connections between them. For this reason, a fundamental aspect of this work is collecting a library of symbols that represent Pneumatics components. The algorithm for performing and ascertaining the schematic for the correctness of each laboratory work is included in this work.

2. MATERIALS AND METHODS

The main software used in the development is the Unity game engine. Unity is widely employed to create games and interactive 3D and 2D experiences, e.g., training simulation, medical and building construction (Li & Tang, 2019). This software includes a wide range of tools and packages allowing to accomplish the designated task entirely. Furthermore, the application includes numerous C# scripts that are written using Rider by JetBrains. The current study is inclusive of a 2D space from which a student accesses the virtual Pneumatics laboratory. The gamification experience provides an opportunity to conduct Pneumatics laboratory works remotely decreasing the necessity of contact learning and the use of physical Pneumatics components. Pneumatics laboratory tasks are transferred into the gamification experience and a student is presumed to construct a schematic in conjunction with a step diagram. To endow the virtual environment with an ergonomic interface, the gamification experience is inclusive of the "Main Menu" for laboratory work selection and advancement observation. Upon starting the gamification application, the user is suggested to select the required subject and subsequently the laboratory work number. This activates the algorithm that allows access to the laboratory works exclusively after the successful completion of the previous task as students are required to accomplish laboratory works consistently. The transition between the laboratory works is initiated automatically and immediately after the total amount of laboratory works is completed. The application allows for the construction of schematics with an unlimited number of attempts. Students can navigate back to the "Main Menu" to either withdraw the gamification experience or revise laboratory works. A representation of the gamification experience system and logic is shown in Figure 1.

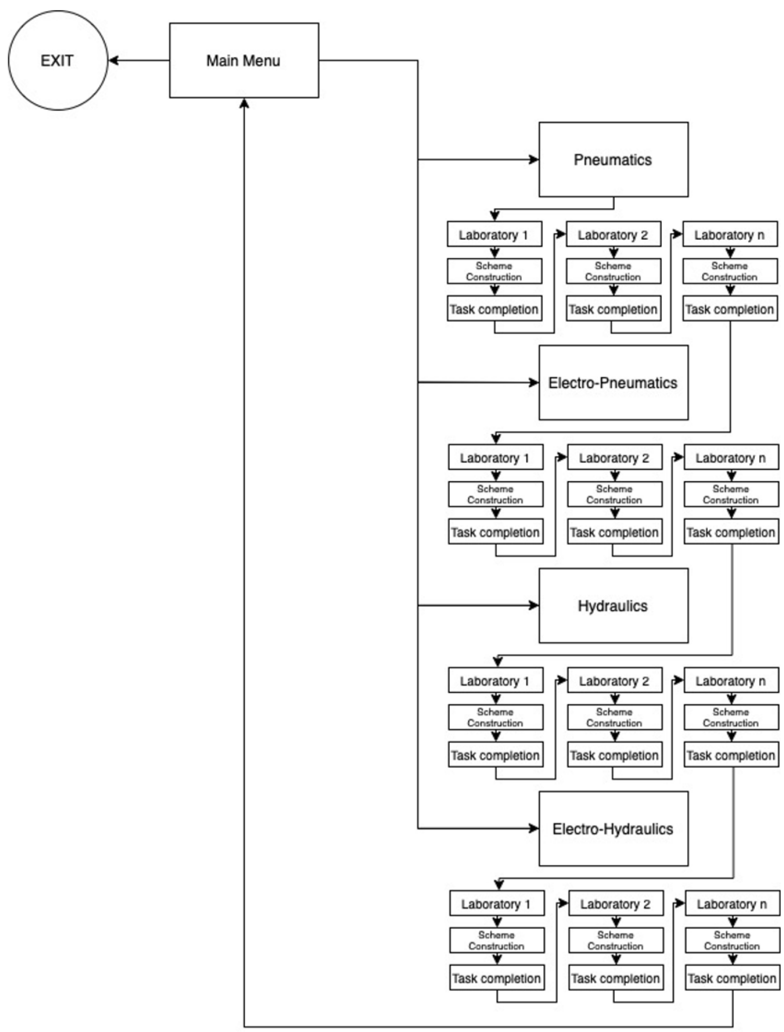

Figure 1. Gamification experience system diagram

The gamification experience is conducted directly on individual Scenes. These can be defined as assets containing all or parts of a game or application within the Unity environment interface (Unity, 2022). Each Scene contains GameObjects, which represent various formats and perform predefined functions, e.g., interact with other objects within the Scene. Such operations can be performed by dint of the Event System. The Event System is a way of sending events to objects in the application based on input, be it a keyboard, mouse, touch, or custom input. The Event System consists of a few components that work together to send events (Unity, 2022). In addition to that, GameObjects can represent colliders, which are used in this work to access the virtual laboratory from the Educational Game Project. Colliders allow for the creation of events that occur in the case of an interaction with the object to which it is assigned.

3. USER INTERFACE

Since the gamification experience on laboratory works is a part of the main Educational Game Project which includes an avatar as well as a 3D model of the university, the access to the laboratory works is accomplished through a user avatar interaction with a Personal Computer in the Virtual and Augmented Reality Laboratory Digital Twin of the IVAR lab at Tallinn University of Technology. This was developed prior to the current research, based on the digitalization and gamification of the student interaction with the university. To activate the interaction a Raycast method is used. Numerous games use the Raycast approach to execute interactions with virtual objects. In broad terms, "Raycasting" can be defined as a method of casting a ray from a specific point, e.g., a main camera, to detect intersections with scenes components called colliders which are attached to specific GameObjects in the scene. The ray turns red in case of encountering an interactable object informing the user he can interact with it. In the case of the PC, this indicates the possibility to access the Pneumatics laboratory work. The representation of Raycasting when detecting an interactable object is shown in Figure 2.

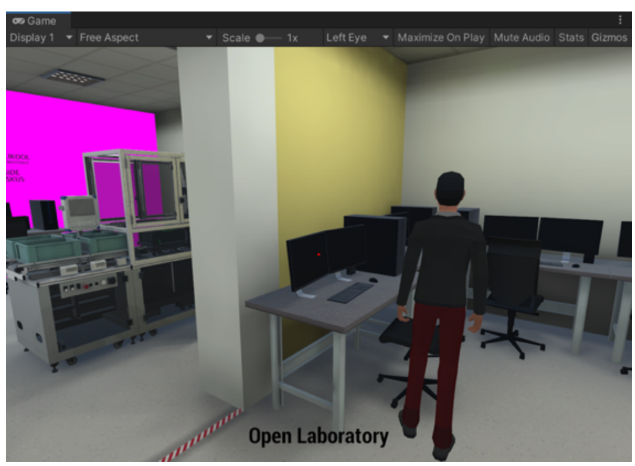

Figure 2: Raycasting once detecting an interactable GameObject

A student executing any laboratory work will be able to visualize the main application user interface (UI). Main UI includes the specific work task requirements, the inventory of the pneumatics symbols, an empty area dedicated to the construction of the schematics as well as buttons that are responsible for the removal of the created connections, reset of the work to the initial state, return to the “Main Menu” and check the composed schematics for correctness. An illustration of the first laboratory work’s initial state description UI can be seen in Figure 3.

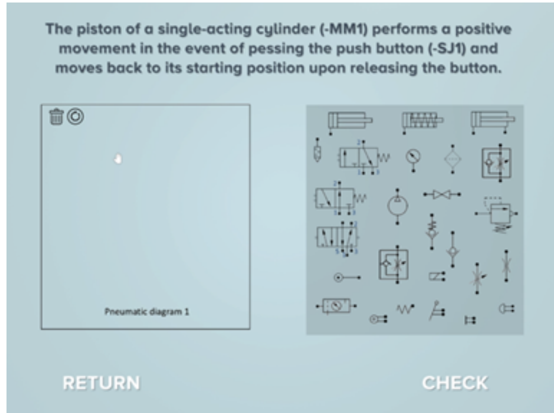

Figure 3. The initial state of the first laboratory work

The application suggests the user construct a schematic based on the selection of the appropriate components from the inventory of the symbols as well as draw the corresponding connections between them. Immediately upon the schematics being composed the student can assess the correctness of the answer by pressing the “check” button in the user interface. In the event of inaccuracy detection, a pop-up notification window appears on the screen. At this point, the student should continue with the construction and modification of the schematic. When the schematic is built correctly the pre-recorded educational video of the detailed illustration of the process of construction and execution of the circuit is visualized in the UI.

3.1 Inventory of symbols

The inventory includes all the components’ symbols that a student would have in a real Pneumatics and Hydraulics Laboratory at Tallinn University of Technology. The illustration of the symbols was obtained from the educational materials on the “Hydraulics and Pneumatics” course and later digitalized. To be able to interact with the symbols, these have to be imported into Unity. Here the textures are transformed into interactable GameObjects called sprites and included in Unity UI components. The term “Sprite” is generally understood as a 2D Graphic object used in two-dimensional application development. The inventory includes single and double-acting cylinders, directional control valves, various control methods, flow control valves, filters, a manometer, a silencer, a compressed air service unit, and a pressure source. Every component is defined as an “Entity” by means of a C# script attached to the corresponding GameObject and the fundamental aspect of the script is storing the list of nodes involved in the component. Depending on the polarity type, the nodes can be distinguished by In, Out, or In-Out which creates a possibility for further deviation between the nodes to compose connections. For instance, nodes of two different components cannot be connected since input nodes connect to output one exclusively.

3.2 User Interface functions

The subsequent step in schematic construction is to create connections between the components. This function is implemented by means of a purchased Unity plugin. Connections are created in the following way. A line is drawn from the first node by clicking on it with the mouse pointer. After this, the node with which the user desires to create a connection is selected allowing for the creation of the connection line, existing as a separate GameObject. The construction originates in a way that the user places the cursor over the necessary node, and presses and holds the left mouse button until a connection line is rendered. The definition of the input of the second component occurs using the method of the program's automatic detection of the closest located node to the mouse position. When the program detects components of type “Entity” included in the Entity List, the list of nodes is read and stored through the “Entity” script. Furthermore, if the node has no existing connections and holds the opposite polarity type, the input point of the second component is attached to the given node that is nearest to the mouse position at the given time. An illustration of the automatic detection of the closest node can be seen in Figure 4. The left side of the illustration exemplifies the case in which the node cannot be selected as an input of the second component due to polarity type incompatibility. On the right side, it may be observed the method the program automatically determines the nearest node of the opposite polarity type to the output of the first component.

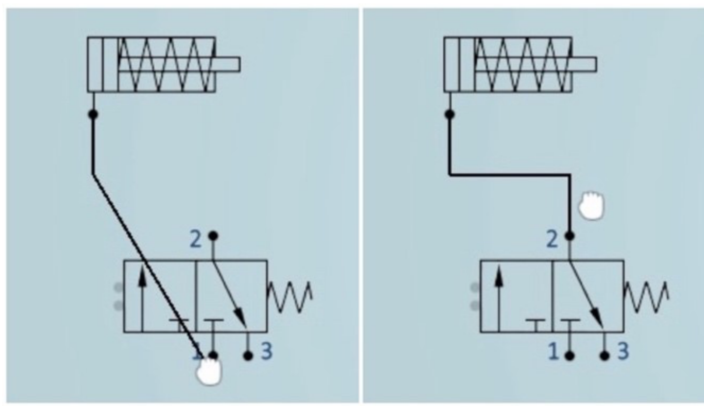

Figure 4. Screen capture of automatic closest node detection

The application allows the removal of already created connections. The “Remove” button is used for this purpose together with a custom script named “ButtonRemoveSelected”. Additionally, a “ResetButton” is added to discard the progress accomplished in schematic composition. The button allows the student to reverse the circuit to its original state at the moment the button is activated.

3.3 Verification of the diagram assembly

Each laboratory work implies the fulfillment of the assigned task. In case of correct assembly of the circuit, the transition to the subsequent task is performed. In order to create a list of nodes to be connected, the “SetupInitialConnectionsEditor” script is developed. The list of connections is designed in a way that it stores the identification number of each connection, as well as information about the correspondence of components’ nodes that are connected. In this study, the script is attached to the UI (User Interface) button titled “CheckButton”. In addition to that, two supplementary GameObjects titled “TryAgain” and “Correct” were created. The “TryAgain” GameObject is the child object of the “Canvas Manager” that represents a pop-up window in case of incorrect completion of the assigned task. The “Correct” GameObject involves a pre-recorded educational video that can be observed by the student in order to understand how the circuit is assembled in a real laboratory. Laboratory works should be streamlined, and since the level of complexity changes incrementally, it is rational to supply access to subsequent laboratory work exclusively in case of successful completion of the previous one.

4. PRELIMINARY ASSESSMENT OF THE COURSE

4.1 "Hydraulics and Pneumatics" course syllabus

The "Hydraulics and Pneumatics" course syllabus consists of theoretical and practical activities prior to taking final exams. Initially, the students are provided with necessary theoretical information, thus they are prepared for the laboratory works which are defined as a practical part of the course.

The practical tasks are carried out by groups of students, usually consisting of two or three individuals, and the assignments are passed with the same team throughout the term. The tasks are designed to introduce the students to the different types of pneumatics, electro-pneumatic, and hydraulics provided in the "worksheet". The solutions should be drawn correctly using the standards for circuit diagrams. Consequently, the teacher supervises the students and provides support in the testing of the composed circuits on the designated board. In fact, all necessary components required for each laboratory work's circuit composition are presented in the class. Students are allowed to use various materials during the practice, but they must defend their work when all the exercises are completed along with respective circuit compositions. Defending the practice is an individual activity and each student is assessed on respective skills and knowledge.

4.2 Application Testing

Once implemented the application was tested to assess usability, efficiency, and probable future improvements. For this purpose, we prepared a custom questionnaire that included an assessment of aspects such as UI efficiency, usability, and user experience. The questionnaire was used among Bachelor students from autumn 2021 and 2022 Pneumatics and Hydraulics course with gender distribution in 2021: female – 16% and male – 84%, and in 2022: female – 17% and male – 83% from the identical location area, namely, Tallinn, Estonia. Students have performed the laboratory works in the form of gamification experience as a part of the MES0085 "Hydraulics and Pneumatics" course. Consequently, the total number of responses is equal to 62, yet about half of the respondents have never experienced the usage of platforms similar to Unity. The results of the questionnaire revealed that 10 participants could not accomplish all the laboratory works. The prime obstacle was the algorithm of circuit composition, namely in the current version the sequence of components' connection lines is essential, and laboratory work is not marked correct if the schematic is not assembled in ascending order.

The main advantages mentioned by the students in the questionnaire were the following:

- opportunity to execute laboratory works remotely, particularly during the pandemic time;
- instant ascertainment of the schematic correctness;
- link of theory with practice by means of a combination of exercises and educational videos;
- ability to walk around the virtual university;
- smaller size and better performance in comparison with other platforms;
- detailed visualization and intuitive interface for educational purposes.

The general level of satisfaction on a variety of aspects is presented in Figure 5.

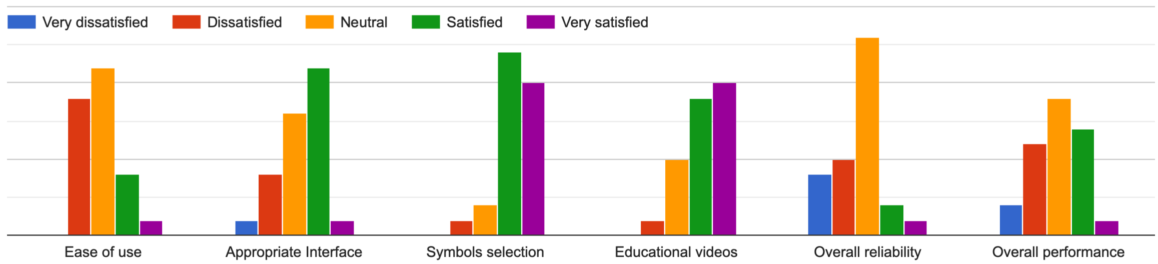

Figure 5: General level of satisfaction

The subject of future development is related mainly to the algorithm of circuit verification which affects such aspects as ease of use, overall reliability as well as performance. In the final analysis, the interface serves as great preparation before the actual laboratory and the gamification experience is overall professional and helpful.

5. LIMITATIONS OF SOFTWARE AND FUTURE DEVELOPMENT

Currently, the gamification experience is inclusive of one shortcoming which is the verification of a schematic. Generally, the functionality of the gamification experience may be expanded, e.g., on the occasion of hovering over a component located in the inventory, its title may be displayed, which would make it possible to remember the designations of the components more effectively. In addition to that, prompts about what is not correct on the schematic would give the student more insight into the progress. Such prompts may represent notifications that either the components are not selected correctly, or the connection lines are not drawn correctly. As an additional feature, it is possible to add navigation to the educational video that would endow the student with the ability to delve deeper into the subject and be more aware of the circuit composition in the physical lab. Furthermore, by parity of reasoning the laboratory works on Hydraulics can be developed, which would enable students to completely perform laboratory works on the “Hydraulics and Pneumatics” course remotely. Henceforth, the laboratory works on Hydraulics should be included in the project, following the modified and finalized algorithm. Additionally, the preservation of the existing progress should be saved at each withdrawal from the gamification experience in order not to mislay the progress obtained.

6. CONCLUSION

The present work was designed to transfer the educational process, namely, the conduct of laboratory works on Pneumatics and Electro-Pneumatics, into the form of a virtual gamification experience. To accomplish this task, the work is integrated into the Educational Game Project developed by the Virtual and Augmented Reality Laboratory at Tallinn University of Technology. Originally, the gamification experience was inclusive of a 3D model of the University and a customizable avatar that could move around in a virtual environment. The model of the Pneumatics and Hydraulics laboratory has not yet been built; thus, a student can acquire access to the laboratory works in the Virtual and Augmented Reality Laboratory.

On the occasion of entering the virtual environment, which represents a 2D gamification experience, a user observes the “Main Menu”, which consists of subject selection between Pneumatics and Hydraulics, as well as a return to the 3D laboratory. At the time of subject selection, a list of numbered laboratory works appears, access to which opens exclusively in case the previous task is completed successfully. At the opening of the laboratory work, the student observes the task in text format on the top of the screen, the inventory of symbols, and the designated place for the schematic composition. The objective is to select the necessary components, transfer them to the schematic and build connection lines. For building connection lines, the "UI Connect" Asset is purchased from the Unity Asset Store and applied as a pattern. The connection line represents a Z-shape line, which is determined by 4 control points in order to improve the appearance of the circuit, and each connection line stores information about the nodes between which the connection is created. Laboratory works are developed hereby two UI buttons are located in the left corner of the schematic that allows to destruct connection lines or revert the work to its initial state. In addition to that, two buttons are placed at the bottom, one of which allows the withdrawal of the gamification experience, while the second is utilized to ascertain the composed schematic for correctness. The verification algorithm is that for each laboratory work, a list of correct connections is initially created in the format of connected nodes, and once each connection is built, the student will be able to observe the pre-recorded educational video. The educational videos are inclusive of an illustration of the components that are necessary to assemble a circuit as well as the process of composition and execution. These videos are implemented thereby the student cannot merely compose a theoretical schematic, but also study the construction process in a real laboratory. In case the schematic is not assembled correctly, the user observes a window with the corresponding information. Upon successful completion of the designated task, access to the subsequent laboratory work acquires and the student can revise the progress accomplished.

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BIOGRAPHICAL INFORMATION

Ivanna Sandyk was born in Ukraine on 27th Aug 2000. She is a graduate of Tallinn University of Technology, Tallinn, Estonia with a Bachelor's Degree in Integrated Engineering in 2021. Ivanna used to work at a top tech robotics company. While pursuing a Master's Degree in Design and Technology Futures, Ivanna is also a project engineer in a PRAMECO project funded by European Union. Her primary research topics are gamification as well as educational environments.

Margus Müür was born in Estonia on 26th Jun 1980. He got a Master's Degree in Electrical Drives and Power Electronics at Tallinn University of Technology, Tallinn, Estonia in 2008. Since 2019 Margus has been working as a lecturer in the field of Robotics and Industrial Automation at Tallinn University of Technology. Previously, he had worked as an engineer at Tallinn University of Technology since 2004. He is the primary lecturer in the MES0085 "Hydraulics and Pneumatics" course. M.S. Müür has been the Estonian main expert for WorldSkills and EuroSkills in the field of Mechatronics from 2007 up to 2017.

Vladimir Kuts received his Ph.D. in Mechanical Engineering from Tallinn University of Technology (TalTech) in 2019. From the Year 2017, Dr. Kuts has been Head of the Industrial Virtual and Augmented Reality Laboratory (www.ivar.taltech.ee) in the Department of Mechanical and Industrial Engineering Department of TalTech. Currently, he is a research fellow at the University of Limerick, Ireland. His main research interests include Industrial Digital Twins synchronized with real industrial equipment such as robots and Virtual Reality technologies for human-robot interaction standards validation. Moreover, he is serving as vice-chair of the IEEE Estonian section.

Yevhen Bondarenko was born in Ukraine on 17th March 1998. He graduated from Tallinn University of Technology (TalTech) with a Master's Degree in Computer Systems Engineering in 2021. Since the Autumn of 2021 Yevhen has started his research as a Ph.D. Student in the TalTech Department of Mechanical Engineering. His primary research is dedicated to the development of brain-computer interfaces for controlling digital twins of industrial robots, however, he is also taking an active part in virtual and augmented reality projects aiming to digitalize educational experiences.

Simone Luca Pizzagalli was born in Italy on the 1st of February 1983. He received the B.S. degree in Architecture and Urban planning at Politecnico di Milano, Italy, in 2005 and M.S Degree in Architectural Design at Delft University of Technology, The Netherlands, in 2007. He attended a specialization course in advanced Human Machine interfaces at Politecnico di Milano and the National Research Council of Italy in 2015. He is currently an early-stage researcher and Ph.D. candidate at the Faculty of Mechanical Engineering of Tallinn University of Technology, Estonia. He has a background in planning and user-centered design of assisted and sensorized living environments, focusing on the health and well-being of frail users during daily life activities. Previously active in the implementation of Virtual and Augmented Reality applications aimed at rehabilitation and training at the National Research Council of Italy, he is now focusing on Digital Twin Virtual and Augmented reality interfaces for Human-Robot Interaction.

Tiia Rüütmann was born in Estonia on 15th March 1959. She graduated from Tallinn University of Technology (TalTech) as a Diploma Engineer in the field of Chemical Engineering and Cybernetics in 1982 and received her second MSc degree in chemical engineering at TalTech in 1992. She defended her Ph.D. in Education (with a specialization in engineering pedagogy) at the University of Hradec Králové, Czech Republic in 2007. Since 2001 Tiia has been working as an associate professor and head of the Estonian Centre for Engineering Pedagogy at TalTech. Her field of expertise and research are engineering pedagogy, STEM & university didactics, laboratory didactics, and innovative methodologies. In 2021 she received IEOM Global Engineering Education Award, and she was invited to share her journey to professional success by writing her chapter in a book published by IFEE/GEDC "Rising to the Top". In 2021 she was elected as the president-elect of the International Society for Engineering Pedagogy (IGIP).

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