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EMERALD

The Education, Scholarships, Apprenticeships and Youth Entrepreneurship

EUROPEAN NETWORK FOR 3D PRINTING OF BIOMIMETIC MECHATRONIC SYSTEMS

INTELLECTUAL OUTPUT O3 - EMERALD REPORT

Project Title	**European network for 3D printing of biomimetic mechatronic systems** **21-COP-0019**
Output	**O3 - EMERALD e-learning VR / AR platform for programming and using biomimetic mechatronic systems**
Date of Delivery	**2023**
Authors	**All partners**

Content

1. Introduction, objectives and tasks of O3

The e-learning virtual laboratory platform conceived in the frame of O3 has been designed especially for anyone who is eager to gain knowledge & expertise in the conceiving, realizing & testing of bio-mechatronics systems for people with special needs (with amputated arms). The e-learning virtual laboratory platform has been conceived by the EMERALD project consortium in such way to be easy accessed & used online. In the context of the pandemic, when physical access to laboratories was restricted, new teaching methods were foreseen to be implemented. In this context, it was intended that the users can easily access the EMERALD e-learning virtual laboratory platform in such way that they will have the feeling as they are being present in the physical laboratories in the end. The e-learning virtual laboratory platform that has been conceived in the frame of O3 (see Fig.1.1) it is not just a place where users can simply look around, but it is a place of a full learning environment. Every digital laboratory room that can be also visualized in VR mode is focused on the presenting of a particular step in the chain of conceiving, realizing & producing of a bio-mechatronic system for people with amputated arms contains lot of different learning materials, starting with VR/AR reality applications that have been conceived with the purpose of helping the user to comprise all the constructing elements of a bio-mechatronic system, up to practical tools on doing VR/AR programming & continuing with other clear explanations with annotations related to the equipment items that are present in different labs & their characteristics (e.g. 3D printer name, model + link to producer), links to videos related to the operating of specific equipment/software, connected to the above mentioned annotations, links to course modules & toolkit (PDF files, results of O1/O2), links from which there can be downloaded freely available/online software programs for CAD, CAE, 3D printing & others. In order to have a logical manner of understanding & following things, a schematic image & one set of instructions have been provided to the users before they are going to access the virtual laboratories as one may notice on the next following link: https://project-emerald.eu/?page_id=404 Actually the way the online rooms have been set up takes users on a full journey for a better understanding the steps that are necessary to be followed for producing bio-mechatronic systems for people with amputated arms, starting with 3D scanning, then continuing with the CAD design, being followed by CAE validation, in close correlation with testing & selecting of the materials, 3D printing of the physical parts, adding of the necessary sensors, assembling of the system, programming, testing & exploring of the conceived system using VR/AR in the end.

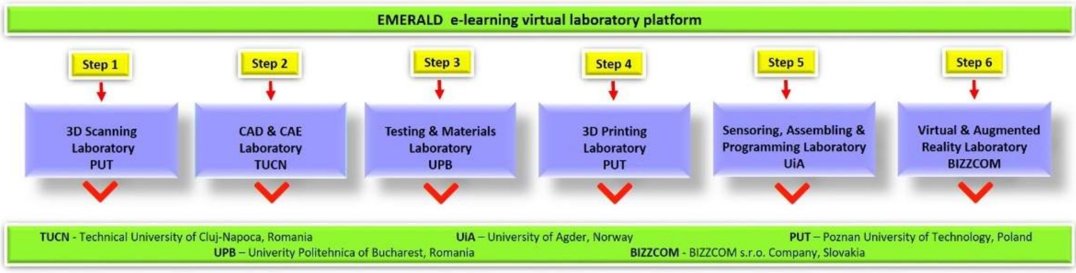

Fig.1.1. Concept of the e-learning virtual laboratory platform

The e-learning virtual laboratory platform has been conceived as one web-based platform that is accessible by WWW browser (see Figure 1.2).

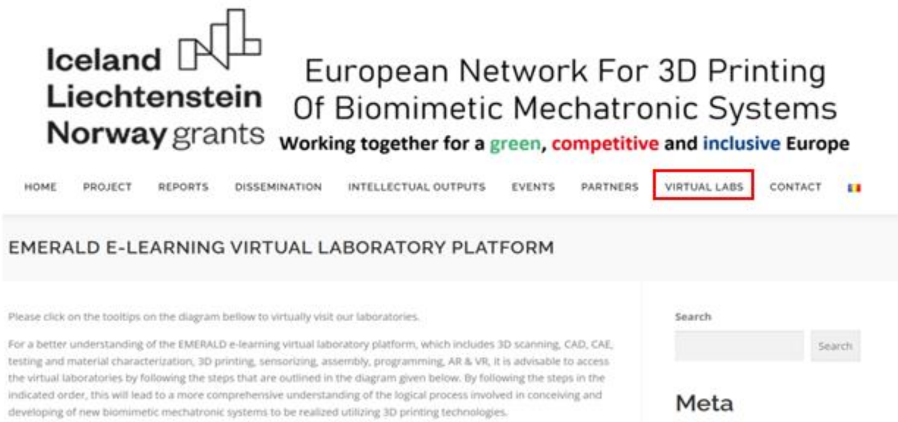

Fig.1.2. Accessing of the e-learning virtual laboratory platform through the www browser

Each institution of the EMERALD consortium has been asked to provide digital image of real laboratory room (possible to be launched also by dedicated external application with the use of VR/AR technology), captured by 360 degree camera, containing basic information about the equipment contained in particular given rooms according to the topic of the room that has been assigned to each institution. Since they had previous experience in building AR applications in particular & in using of Web learning methods, Bizzcom company (Slovakia) has been assigned as leading institution for producing the e-learning virtual laboratory platform.

The distributing of the virtual laboratory rooms for the EMERALD e-learning platform has been realized by taking into consideration the experience of the EMERALD consortium partners &

their previous collaborative work done with the other partners in the consortium within the EMERALD project until this phase of the project (see Figure 1). In this way, Poznan University of Technology (PUT) has taken the main responsibility in preparing the virtual laboratory room related to the 3D scanning process, while the Technical University of Cluj-Napoca has been assigned to take care about the next following steps (laboratory of CAD/CAE), dealing with both design & engineering aspects. University Politehnica Bucharest (UPB) was given the main role of testing & assigning of the **0materials, while PUT (which have more than 40 3D printers in their laboratory) have been assigned to take the responsibility of realizing the 3D printing laboratory room. Taking into consideration the experience that the University of Agder (UiA) has concerning the sensorizing, assembly & programming domain (as well as in bio-mechatronics), they have been assigned with the main role of organizing of specific educational tools & methods that are related to this domain in their virtual laboratory. Last, but not least BIZZCOM, which have high experience with the immersive technologies, have taken the responsibility of preparing the AR/VR virtual laboratory room (in cooperation with PUT). In order to provide clarity concerning the challenging developing process of bio-mechatronic systems for people with amputated arms, on the EMERALD official website that is hosting the e-learning virtual laboratory platform it has been featured a well-organized schematic & guide (with specific laboratories assigned to each partner of the EMERALD consortium), in order to lead users to follow the virtual laboratories in a logical way, by accessing step-by-step each laboratory (as well as all facilities that are being offered in each laboratory) so as they can comprise easier all steps that the conceiving, developing, producing & testing of bio-mechatronic systems for people with amputated arms are assuming to.

2. EMERALD e-learning VR / AR platform

2.1. 3D scanning laboratory room (PUT)

3D scanning virtual laboratory room which has been assigned to the Poznan University of Technology as one may notice in Figure 2.1.1 can be accessed from the www interface of the EMERALD project (https://project-emerald.eu/?page_id=404) or directly by accessing the next following link: https://my.matterport.com/show/?m=NXHcatKcdW7&sr=-2.95,.1&ss=37

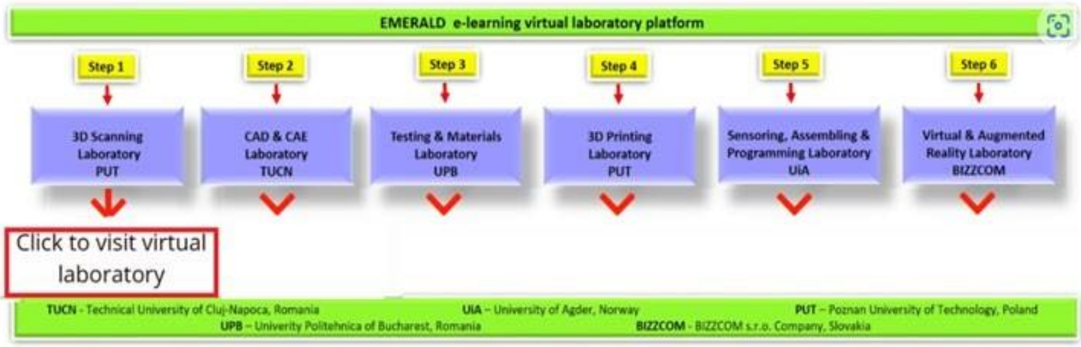

Figure 2.1.1. Accessing of the 3D scanning virtual laboratory room from the e-learning platform

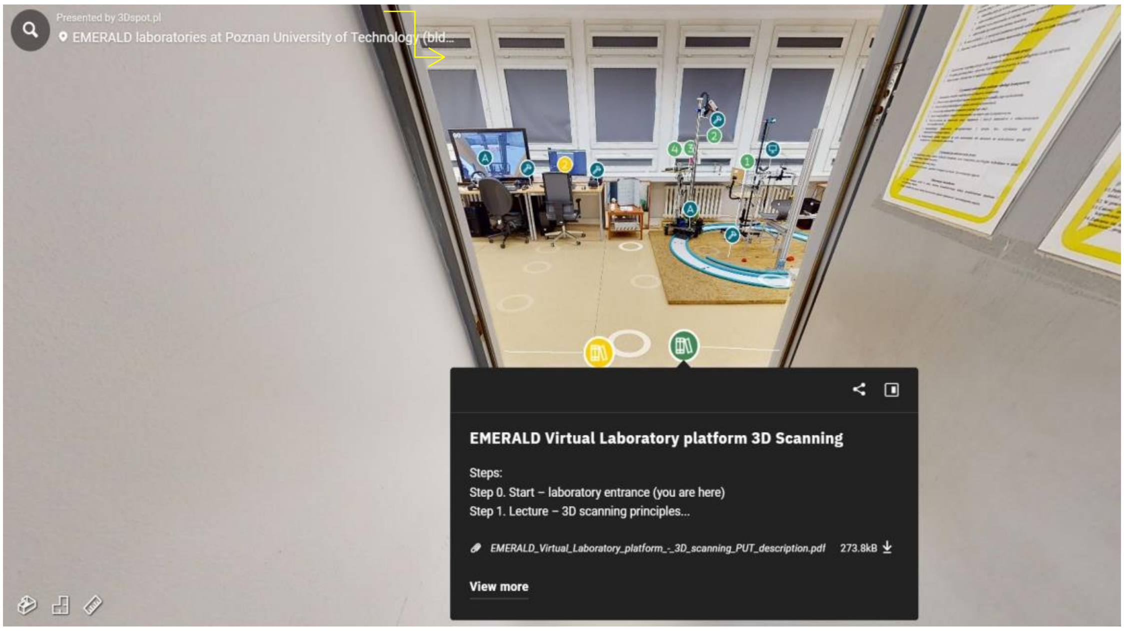

Figure 2.1.2. Main entrance of the 3D scanning laboratory of PUT

The 3D scanning virtual laboratory room at PUT that can be seen in Figure 2.1.2, has been realized using Matterport Pro camera, the captured images undergoing in further processing using Matterport software, allowing the integration of educational materials related to 3D scanning for the bio-mechatronic components that have been developed within the EMERALD project related to this topic in particular. The laboratory itself is also a XR laboratory (containing various Virtual, Augmented and Mixed Reality devices), and as such is used as a multi-purpose laboratory – it will be referred to in one of the next chapters.

Disclaimer: This results was realised with the EEA Financial Mechanism 2014-2021 financial support. Its content (text, photos, videos) does not reflect the official opinion of the Programme Operator, the National Contact Point and the Financial Mechanism Office. Responsibility for the information and views expressed therein lies entirely with the author(s).

The e-learning virtual laboratory platform dedicated to the 3D scanning stage in particular offers an enriched educational experience that is tailored to the first step that is necessary to be followed concerning the developing of bio-mechatronic systems destined for people with special needs (with amputated arms) such as orthoses, prostheses or robotic arms. The main aim of the platform in relation to 3D scanning aims to familiarize the users and facilitate their comprehensive learning and understanding by providing them a smooth advancement and gradual progression concerning the teaching materials and resources the users are following and are accessing on the e-learning virtual laboratory platform. In this sense, upon entering the 3D scanning virtual laboratory room, users gain access to a structured curriculum that starts with foundational course materials that cover the basics of 3D scanning methods, then they have access to highly practical laboratory tutorials, completed with toolkits and instructional videos that are providing the users step by step information data on how they have to do the 3D scanning of specific bio-mechatronic components for people with special needs (like orthoses, prostheses and robotic arms,) and finally users have access to 3D scanned library of models, which corresponds to the models that are being presented in the tutorials, toolkits and instructional videos, along with information for accessing of various software programs that the users can download and work with them, to do preparing of files. The course of 3D scanning available in the laboratory has been divided into 4 main steps (Figure 2.1.3), with some additional information available besides these steps: Step 0. Start – laboratory entrance, Step 1. Lecture – 3D scanning principles, Step 2. 3D scanning of human limb – video , Step 3. Software for scanning data processing, Step 4. Tutorials on limb scan data processing.

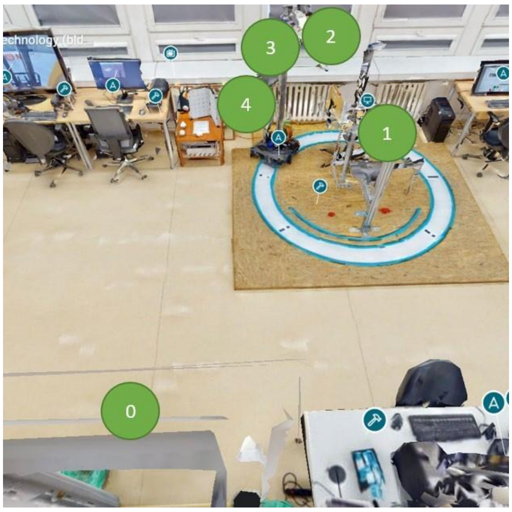

Figure 2.1.3. 3D scanning – steps of the course

Step 0, accessible right after entering the laboratory (green marker), contains overview of all the other steps and a short document with information for the Virtual Laboratory user. Direct link to this starting point is here: https://my.matterport.com/show/?m=NXHcatKcdW7&sr=-.62%2C.96&ss=63&tag=wOmz3i7mWRc&pin-pos=-20.76%2C1%2C2.22

The e-learning course available on the virtual platform offers a meticulously structured and all-encompassing approach to the field of 3D scanning, with a specific emphasis on its application in the field of prosthetic device design as one may notice in Figure 2.1.4.

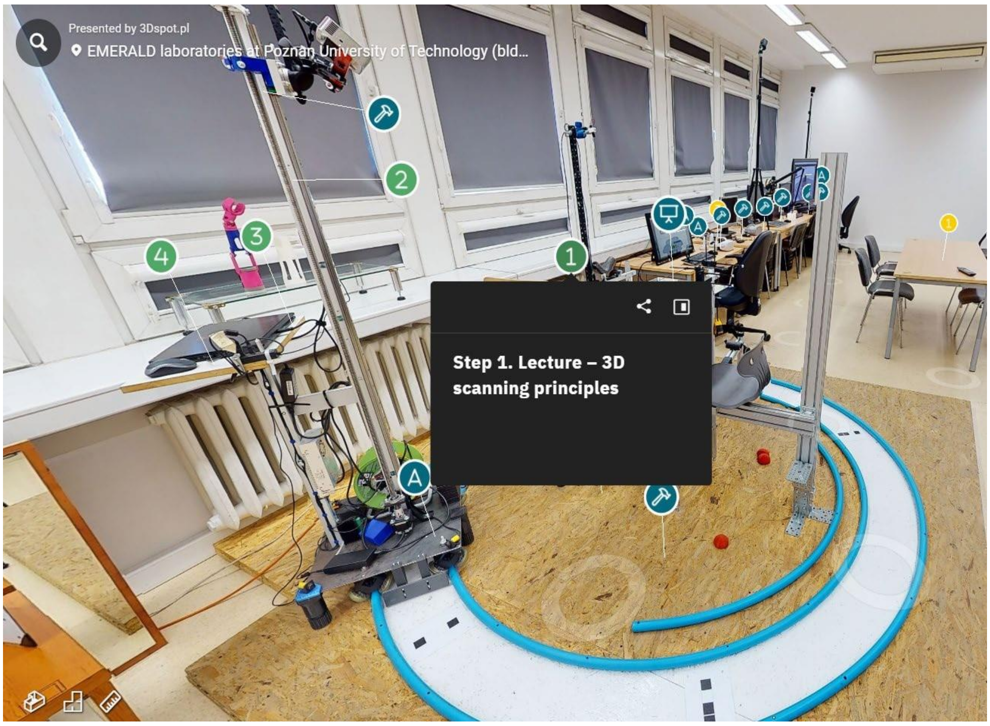

Figure 2.1.4. 3D scanning lecture accessing

This comprehensive course is thoughtfully divided into several interconnected steps, each contributing to a holistic understanding of the subject matter. The journey begins with a fundamental introduction to prosthetic design, setting the stage by underscoring the crucial role of customization and individualization in this field. This initial phase is highly exemplified to visually comprise the importance of tailoring prosthetic devices to meet the needs of people with amputated arms.

As the course is continuing, transition into the complex world of 3D scanning techniques is being made. These techniques are meticulously categorized into two distinct categories: contact and non-contact methods. The nuances of each method are explored in depth, offering students a profound understanding of the subject matter. This phase of the course also features comprehensive discussions on specific 3D scanning modes, including CT, MRI and photogrammetry, with visual aids provided in Figure 2.1.5.

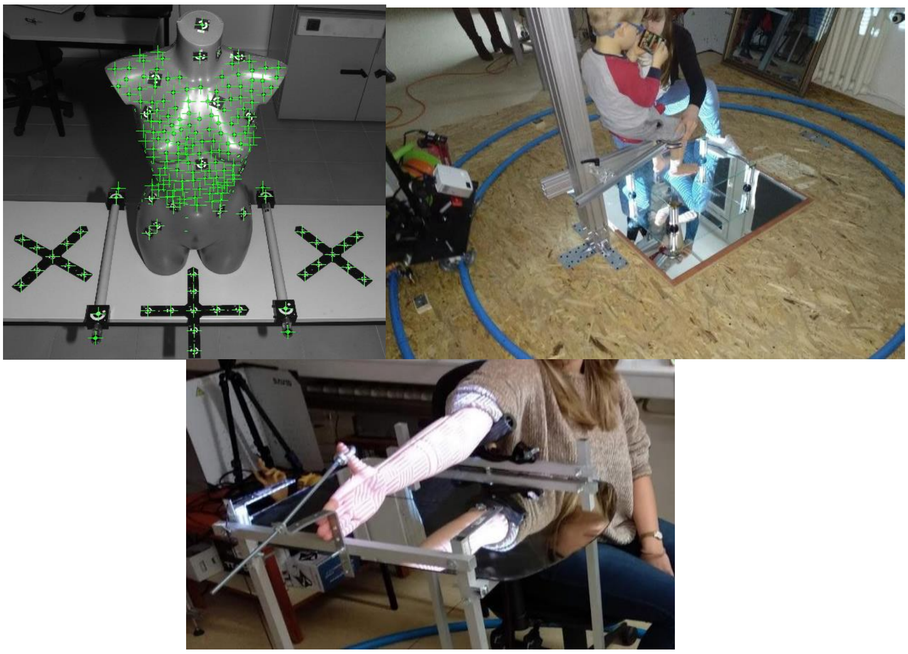

Figure 2.1.5. 3D scanning processes examples detailed in the presentation

Building upon this foundation, the course takes a deep dive into the field of data processing in prosthetic design. This step encompasses a broad spectrum of essential topics, including data formats and processing steps. Students are guided through the stages of segmenting DICOM data and transforming point clouds into complex 3D models, while in addition to theoretical knowledge, the course introduces learners to a suite of indispensable software tools including Slicer, MIMICS, MeshMixer, and MeshLab. This hands-on exposure equips students with practical skills for navigating these software platforms effectively.

An important twist in the course is given by the state-of-the-art review of 3D scanners designed for human body parts. This segment not only traces the evolution of these scanning devices but also highlights the transition from entry-level options to advanced professional-grade scanners.

Complementing the theoretical aspects of the course are tutorial videos that offer a practical dimension to the learning experience. These videos are meticulously segmented, with each segment offering a detailed exploration of various facets of the scanning process. The initial segment focuses on the setup and preparation of patients, demonstrating the utilization of the David SLS-2 scanner. Figure 2.1.6 provides a visual representation of the patient scanning rig setup, ensuring students comprehend the critical initial steps in the scanning process.

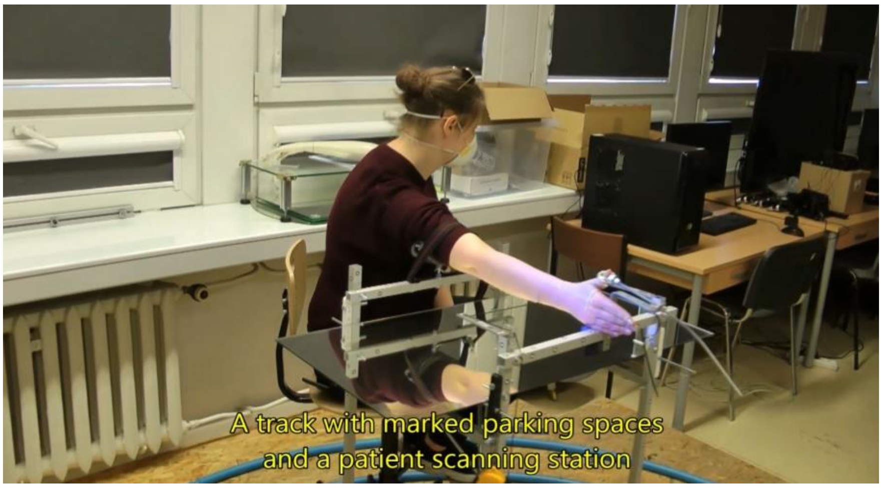

Figure 2.1.6. Tutorial video – patient scanning rig

Continuing on this journey, the video is doing transition to a comprehensive explanation of the scanning methodology. This includes a meticulous breakdown of scanner movements, data collection from diverse positions, and intricate software interactions that are integral to the process. Visual aids concerning the AutoMedPrint software and illuminate the scanning process with the David SLS-3 scanner, respectively are being provided in the course (Figure 2.1.7). The second significant part of the video takes a fascinating turn by delving into the use of a manual 3D scanner, the EinScan Pro. This segment is richly detailed in the course, offering an in-depth look at the software's operation during the scanning process. Additionally, the video features a practical demonstration of hand scanning, providing a real-life scenario that brings the scanning process to life.

This instructional video serves as a vital resource, particularly for students equipped with similar scanning devices. The detailed descriptions and hands-on demonstrations provide a clear pathway for learners to not only grasp but also efficiently operate the software and hardware essential for 3D scanning of human limbs.

Figure 2.1.7. Tutorial videos – scanning with David SLS-3 and EinScan Pro

Following the instructional video, the course seamlessly goes into its third phase, which revolves around software for 3D scanning data processing. This segment, as shown in Figure 2.1.8, guides students on accessing open-source and freeware software such as GOM Inspect and MeshLab. These software tools play a pivotal role in processing 3D scanning meshes, equipping students with the practical skills required for data manipulation.

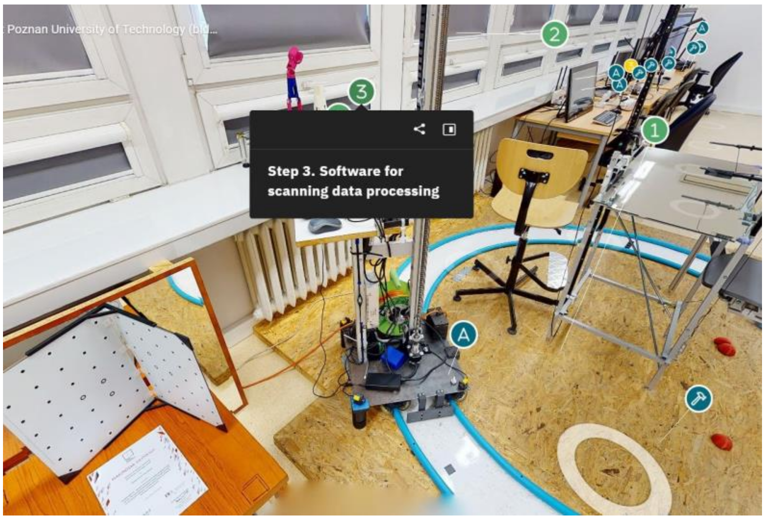

Figure 2.1.8. 3D scanning – software instruction accessing

The fourth phase immerses students in hands-on laboratory work centered on 3D scan data processing. This section encompasses comprehensive instructions and tutorials for processing scanned data using MeshLab software. Within this phase, students engage in critical operations such as data selection, cleaning, hole closing, and mesh reconstruction.

Furthermore, it highlights MeshLab's macro recording capabilities, allowing users to efficiently reutilize and modify macros, thereby enhancing the efficiency of the data processing workflow.

The 3D scanning laboratory section of the e-learning platform is further enriched by a selection of additional teaching materials, meticulously designed to deepen students' comprehension and practical skills in 3D scanning. These resources are tailored to the specific goal of creating customized biomechatronic devices like prostheses. One of the standout supplementary materials is a Virtual Reality (VR) executable application, as shown in Figure 2.1.9.

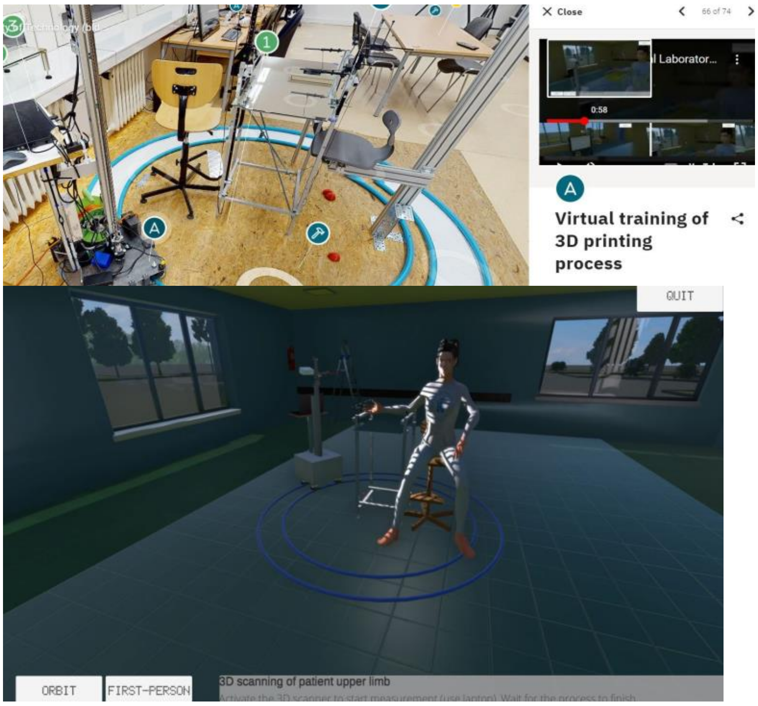

Figure 2.1.9. Interactive Virtual Reality tutorial application – to be downloaded from the platform

This interactive tutorial transcends traditional learning methods by immersing students in a virtual environment where they can fully immerse themselves in the entire process of working with the AutoMedPrint system. This encompasses aspects of 3D scanning, design, and 3D printing. The VR experience empowers students to independently explore and understand the scanning procedure in a highly engaging and hands-on manner, fostering a deeper level of comprehension.

2.2. CAD / CAE laboratory (TUCN)

Computer Aided Design / Computer Aided Engineering (CAD / CAE) virtual laboratory room which has been assigned to the Technical University of Cluj-Napoca, as one may notice in Figure 2.2.1 can be accessed from the www interface of the EMERALD project (https://project-emerald.eu/?page_id=404) or directly by accessing the next following link:

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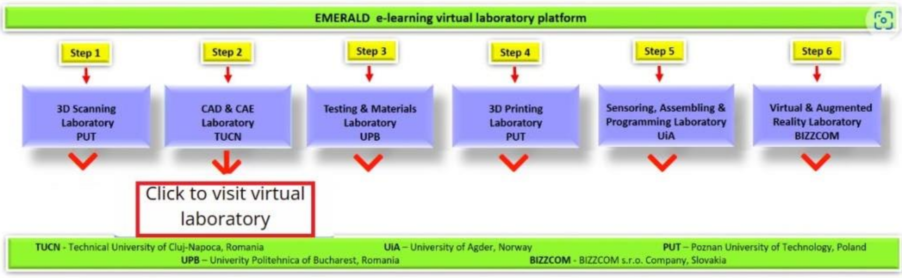


Figure 2.2.1. Accessing of the CAD/CAE virtual laboratory room from the e-learning platform

The Virtual Laboratory tour begins at the entrance of the TUCN main building, as shown in Figure 2.2.2. Upon entering the building through the main corridor, one may access the CAD/CAE virtual laboratory of TUCN, as shown in Figure 2.2.3.

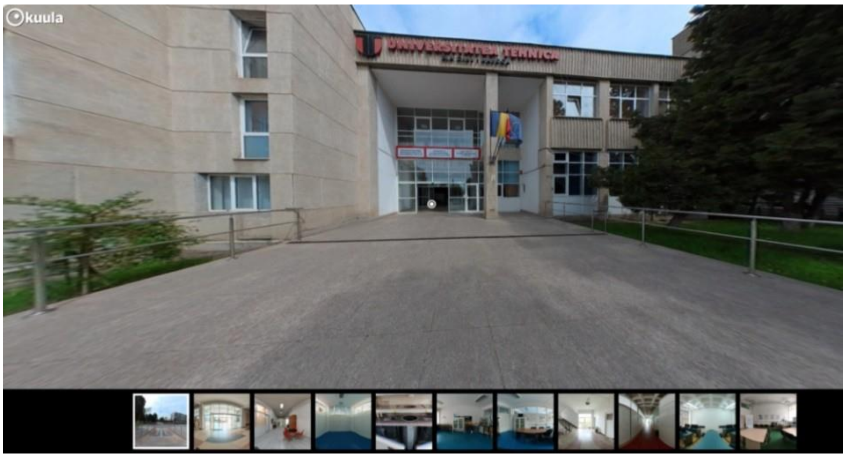


Fig.2.2.2. Entrance of the TUCN main building

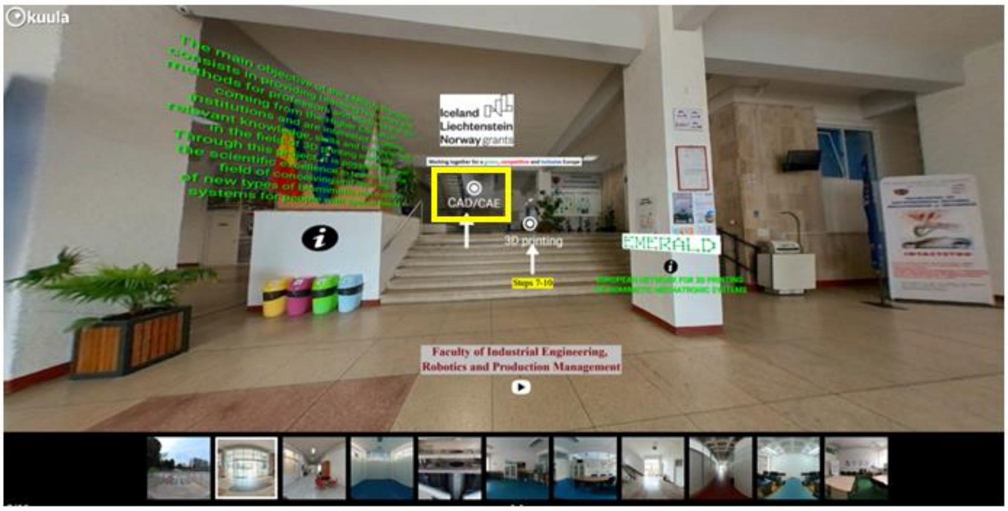


Fig.2.2.3. Access to the CAD / CAE laboratory (TUCN) from the main corridor

The CAD/ CAE virtual laboratory room at TUCN that can be seen in Figure 2.2.4 has been realized using Insta 360 camera, the captured images undergoing in further processing using Kuula software, allowing the integration of educational materials related to CAD / CAE for the bio-mechatronic components that have been developed within the EMERALD project related to these topics.

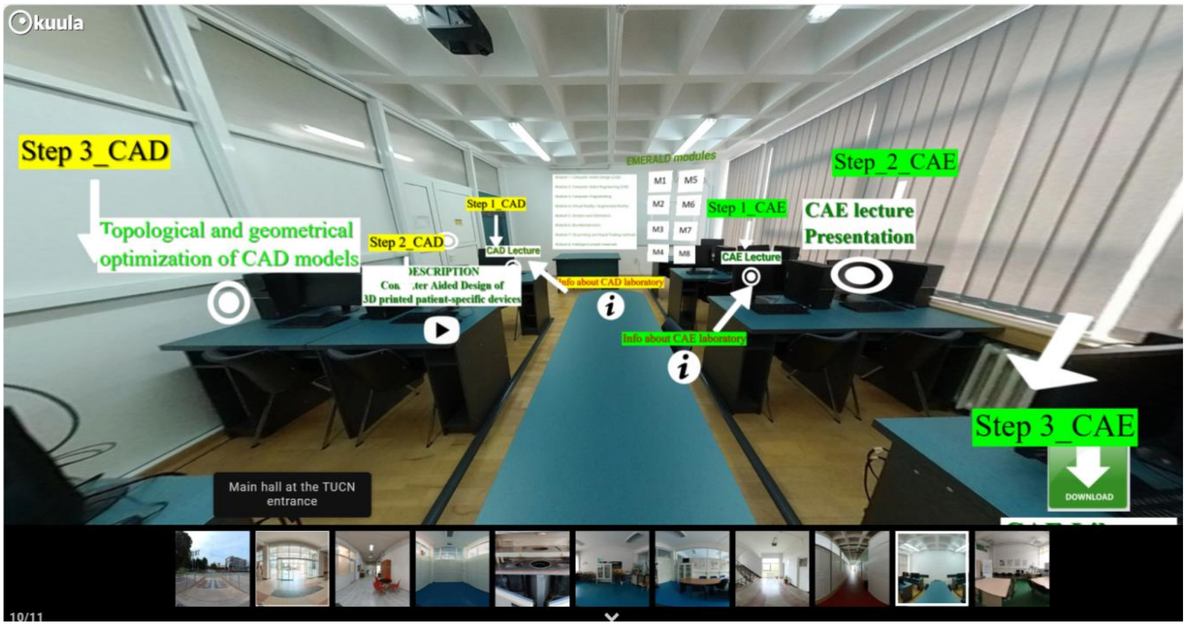


Figure 2.2.4. CAD / CAE laboratory of TUCN

The e-learning virtual laboratory platform dedicated to the Computer Aided Design (CAD) stage followed by Computer Aided Engineering (CAE) in particular offers an enriched educational experience that is tailored to the design of bio-mechatronic systems destined for people with special needs (with amputated arms) such as robotic arms, orthoses and prostheses, focusing on the necessary steps that are particularly necessary to be followed after the initial 3D scanning process of patients. The main aim of the platform in relation to CAD / CAE aims to familiarize the users and facilitate their comprehensive learning by providing them a smooth advancement and gradual progression concerning the teaching materials and resources the users are following and are accessing on the e-learning virtual laboratory platform. In this sense, upon entering the CAD / CAE virtual laboratory room, users gain access to a structured curriculum that tarts with foundational course materials that cover the basics of CAD, then they have access to highly practical laboratory tutorials, completed with toolkits and instructional videos that are providing the users step by step information data on how they have to do the designing of specific bio-mechatronic components for people with amputated arms (like robotic arms, orthoses, prostheses) and finally users have access to CAD / CAE library of models, which corresponds to the models that are being presented in the tutorials, toolkits and instructional videos, along with information for accessing of various CAD/ CAE software programs that the users can download, replicate the CAD / CAE steps they are seeing being made in the instructional materials or modify them in a very stimulative, creative or innovative way, by working further on their own case studies they have been generated in this way by using the EMERALD e-learning virtual laboratory resources.

The resume of the e-learning course on bio-mechatronic systems for peoples with special needs, particularly those with amputated arms, is mainly focused around CAD (Computer-Aided Design) lecture. This lecture serves as the cornerstone of the course, providing learners with a solid foundation in CAD and 3D modeling, specifically tailored to the design of bio-mechatronic systems, including prostheses and orthoses. The lecture comprehensively covers various modeling techniques, including solid modeling, surface modeling, hybrid modeling, wireframe modeling, and mesh modeling, each tailored to specific design needs. It emphasizes the importance of assembly in creating complex models and delves into key CAD software programs, such as Autodesk's Inventor, SolidWorks, Fusion 360, MeshLab, and GOM Inspect, elucidating their roles in CAD and mesh modeling. Practical examples, like the "shell" and "spline" approaches to orthosis design, showcase the application of these concepts (Figure 2.2.5).

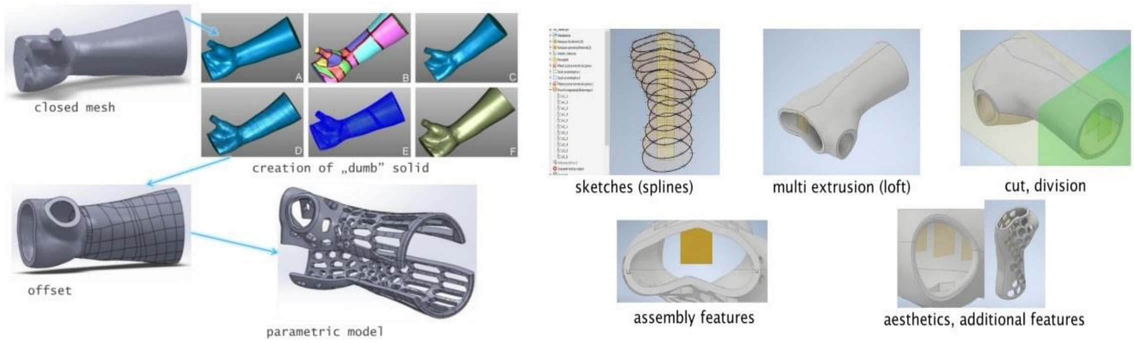
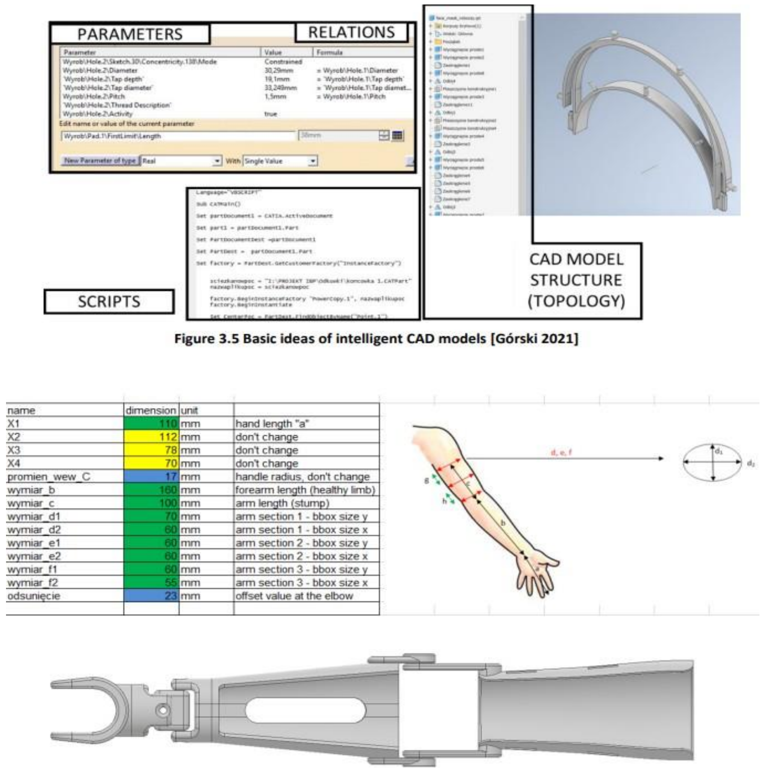


Figure 2.2.5. „Shell" and "spline" approach of the orthoses

Additionally, the lecture highlights the role of automation in medical product design, exemplified by the AutoMedPrint system developed by Poznan University of Technology, a groundbreaking system integrating 3D scanning and printing for efficient prostheses and orthoses production, particularly beneficial for pediatric patients (Figure 2.2.6).



name	dimension	unit	
X1	110	mm	hand length "a"
X2	112	mm	don't change
X3	78	mm	don't change
X4	70	mm	don't change
promien_wew_C	17	mm	handle radius, don't change
wymiar_b	160	mm	forearm length (healthy limb)
wymiar_c	100	mm	arm length (stump)
wymiar_d1	70	mm	arm section 1 - bbox size y
wymiar_d2	60	mm	arm section 1 - bbox size x
wymiar_e1	60	mm	arm section 2 - bbox size y
wymiar_e2	60	mm	arm section 2 - bbox size x
wymiar_f1	60	mm	arm section 3 - bbox size y
wymiar_f2	55	mm	arm section 3 - bbox size x
odsunięcie	23	mm	offset value at the elbow

Figure 2.2.6. AutoMedPrint system used for designing of the orthoses and prostheses

The course further advances students' understanding through additional lectures, presentations, and practical laboratory work. An additional lecture presentation explores the AutoMedPrint system in depth and goes deeper into CAD design for various case studies, especially for patients with amputated arms. This presentation provides comprehensive insights into design engineering, engineering-to-order, and individualized design concepts, emphasizing their significance in bio-mechatronic system design. It also covers CAD stages post-3D scanning, including surface deletion, hole closing, and mesh repairing, crucial for individualized design. The presentation offers detailed information on the AutoMedPrint system, highlighting its integration of innovative techniques and programming languages for automated bio-mechatronic component design.

The third step of the CAD section introduces a lecture presentation focused on Topological and Geometrical Optimization, essential for designing bio-mechatronic systems like robotic arms, orthoses, and prostheses. This module emphasizes the importance of topology optimization, a structural technique that strategically distributes material within products to enhance efficiency and customization. The lecture also explores lattice structures, different lattice types, and their benefits in bio-mechatronic systems. The Curve-Based Method (CBM) and Pattern-Based Method (PBM) are explained for scaffold 3D model creation, with practical applications showcased.

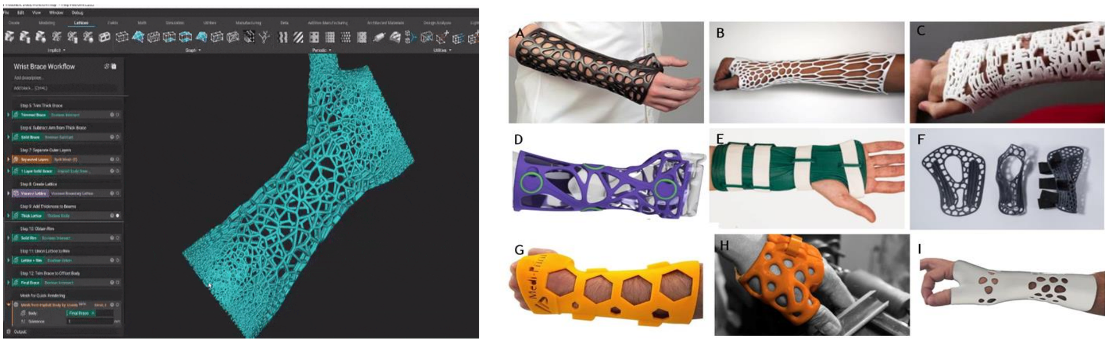


Fig.2.2.7. Topology optimization used for realizing of the orthoses

In the fourth step of the CAD section, students transition from theory to practical application, engaging in hands-on laboratory work for designing bio-mechatronic systems. This step provides access to a variety of CAD models, accessible via a Google Drive link, allowing students to download and customize them for enhanced aesthetics, functionality, or design. CAD software packages necessary for laboratory exercises, including Autodesk Inventor, SolidWorks, and Mesh Lab, are

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linked to, offering students free access. In the fifth step, the course shifts to practical laboratory work, guiding students through the process of designing bio-mechatronic systems, particularly for people with amputated arms. It offers comprehensive CAD toolkit manual, instructional videos, and exercises linked to CAD models on Google Drive, focusing on designing a modular prosthesis adaptable for pediatric and adult users (see Figure 2.2.8).

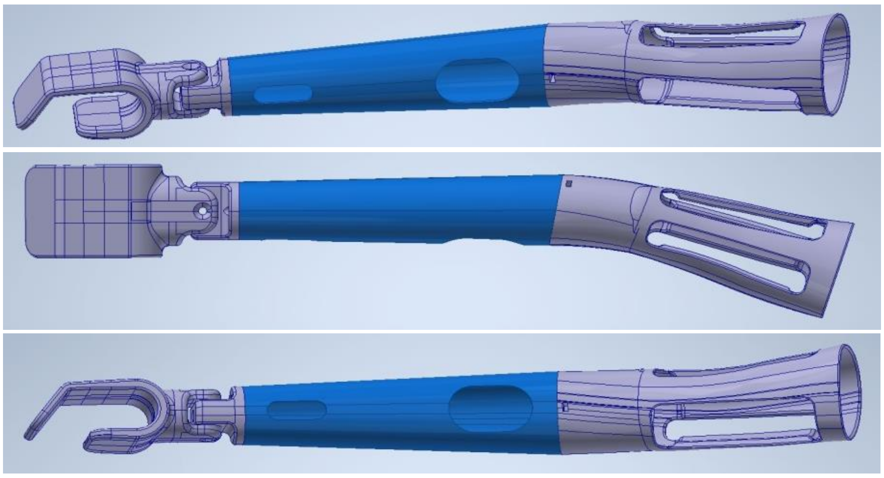

Figure 2.2.8. The final model of the prosthesis realized using MeshLab software.

The toolkit manual covers the precision design of key components, like the forearm section and C-handle, using Mesh Lab. It also explains the design process and modifications for enhanced grip stability and comfort, essential for activities like cycling. Furthermore, the toolkit discusses the CRS socket's transformation for adult use in cycling. To enhance practical learning, the course offers additional laboratory support materials under the O3 framework. These resources include tutorials focused on CAD modeling using Autodesk Inventor, providing step-by-step instructions for modeling bio-mechatronic components like orthoses and prostheses (Figure 2.2.9). The tutorials emphasize personalization for real patients, covering parametric design requirements, lattice structure integration, and cutting operations. They encourage students to apply their creativity and problem-solving skills, fostering innovation in bio-mechatronic system design. In this way the e-learning course equips students with a comprehensive understanding of CAD in bio-mechatronic system design, providing theoretical knowledge, practical laboratory work, and valuable resources for designing specialized devices to improve the lives of people with special needs in the end.

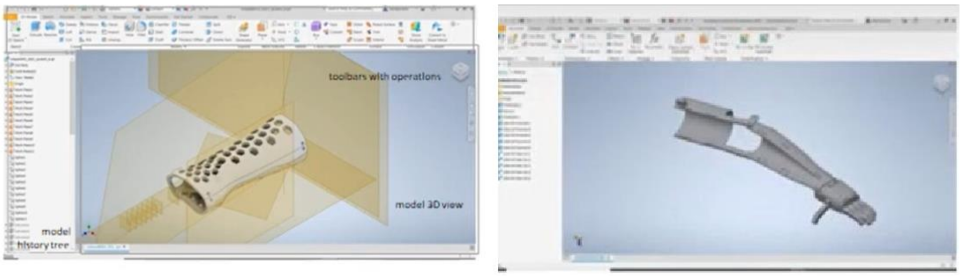

Figure 2.2.9. Bio-mechatronic components (orthoses, prostheses) given in the tutorials

In Step 1 of the CAE (Computer Aided Engineering) section, the e-learning course provides a foundational understanding of CAE and Finite Element Methods (FEM). It emphasizes the significance of engineering calculations and introduces methods like Finite Element Method (FEM) as a powerful tool for solving complex engineering problems. FEM simplifies large problems by breaking them down into smaller elements and is widely adopted for its versatility. The course covers setting up and solving problems with FEM using modern software, including mesh creation, application of forces and constraints, and equation solving.

The Finite Element Analysis (FEA) aspect of CAE is provided as critical tool for simulating material and structural responses. A case study of a wrist hand orthosis is analyzed using SolidWorks Simulation to determine stress distribution and deformation under different force levels. The course outlines the main steps of FEA, including defining material properties, mesh generation, and interpreting results (Figure 2.2.10).

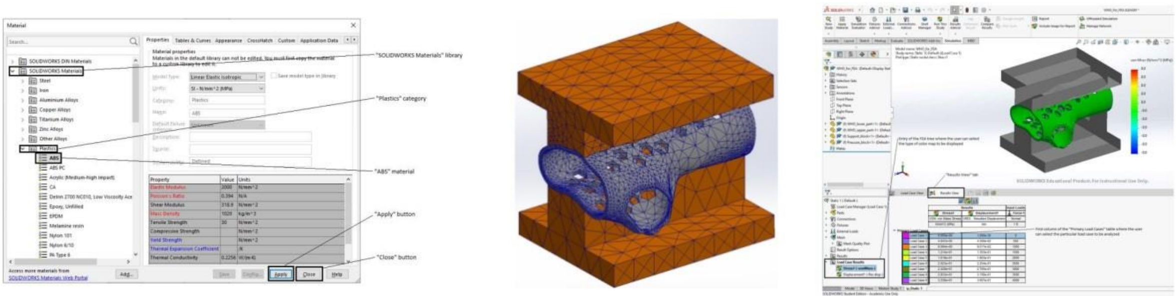

Figure 2.2.10. Defining material properties, mesh generation, and interpreting results in CAE

In Step 2, an additional presentation focuses on practical CAE applications in case studies involving real patients. It introduces professional CAE software programs like ABAQUS and ANSYS and explores specific steps required for diverse case studies, including robotic arms, bone structures, and implants. The presentation highlights the importance of CAE in material selection for 3D printing.

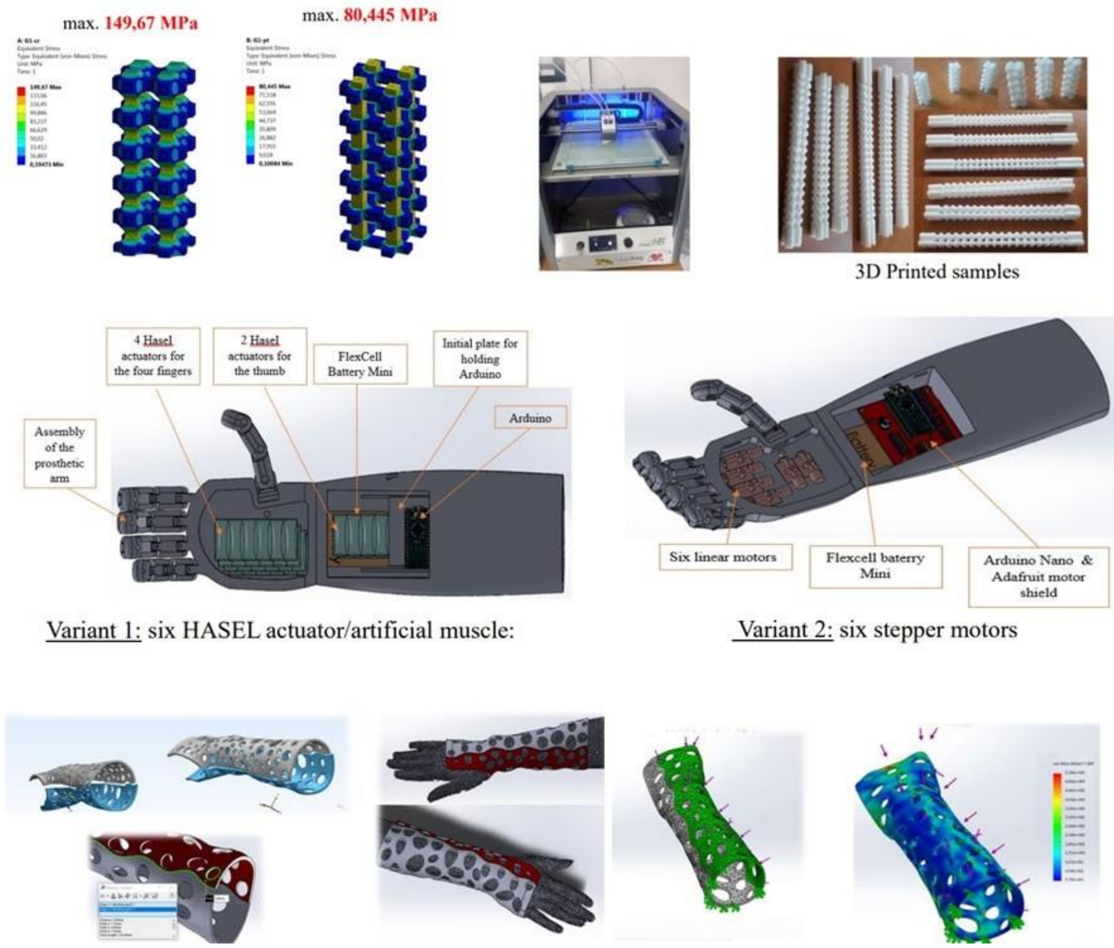

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Figure 2.2.11. CAE in material selection for 3D printing

Step 3 involves hands-on laboratory work and teaching resources. A toolkit manual guides students through CAE analysis using SolidWorks Simulation, focusing on an upper-limb prosthesis subjected to a tensile test. Load cases simulating different traction forces are applied, and results are visualized as von Mises stress distribution. A webinar format provides a dynamic explanation of the CAE analysis. In Step 4, a tutorial by PUT focuses on CAE analysis using Autodesk Inventor for a bicycle prosthesis. This tutorial allows students to compare results between different software programs. It assesses the prosthesis's ability to withstand static loads, such as leaning on bicycle handlebars. An Autodesk CAE video tutorial provides detailed instructions on creating new parts or scenarios for CAE analysis in Autodesk Inventor. Another instructional video demonstrates CAD modifications and CAE analysis for a hand orthosis made of ABS material by 3D printing (Figure 2.2.12).

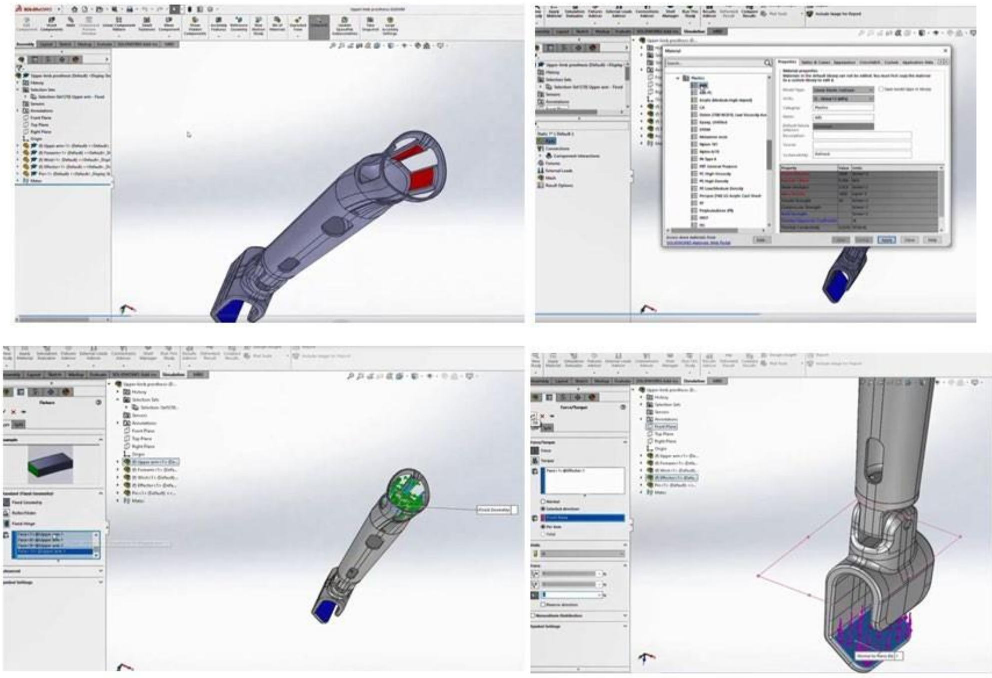

Figure 2.2.12. Tutorials for CAE analyses

In the CAE virtual laboratory, students apply learning resources to conduct their own CAE analyses on various CAD models. These projects showcase student innovation and skill development, with examples featuring different types of lattice structures and materials. These practical examples highlight the real-world utility of the educational resources and emphasize the importance of hands-on experience in CAE. The EMERALD e-learning platform encourages an innovative approach to learning and problem-solving in the field of CAD / CAE.

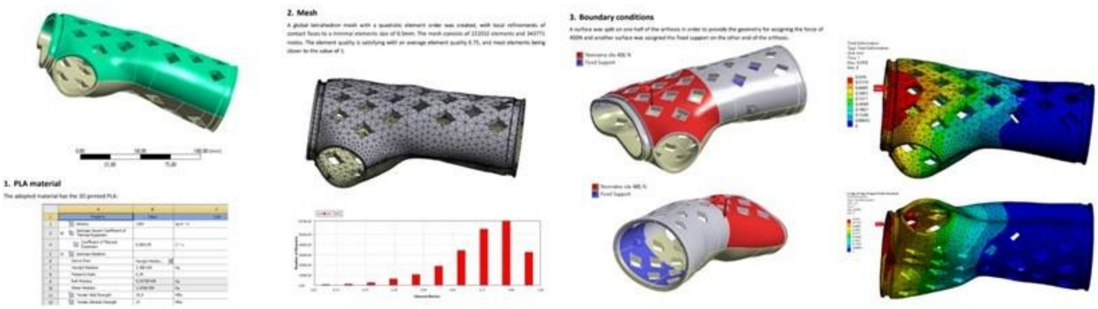

Figure 2.2.13. CAD / CAE innovative approach to learning and problem-solving

2.3. Testing & Materials virtual laboratory room (UPB)

Testing & Materials virtual laboratory room which has been assigned to the University Politehnica Bucharest (UPB), as one may notice in Figure 2.3.1 can be accessed from the www interface of the EMERALD project (https://project-emerald.eu/?page_id=404) or directly by accessing the next following link:

https://bizzcom.viewin360.co/share/collection/7JhlB?logo=0&info=0&fs=1&vr=1&sd=1&initload=0&thumbs=1

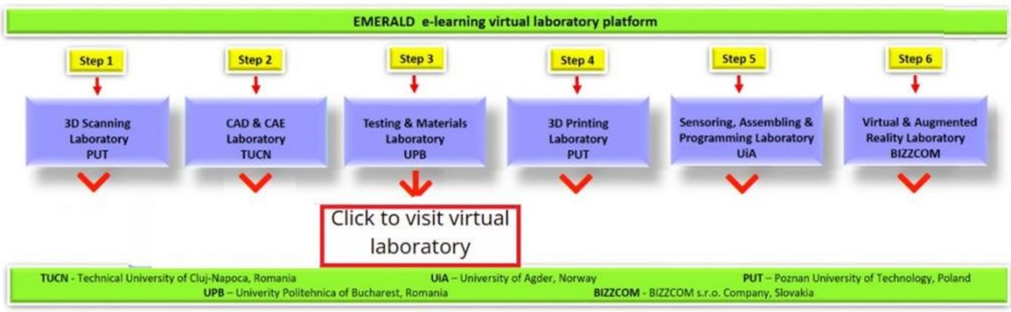

Figure 2.3.1. Accessing of the Materials characterization & testing virtual laboratory room from the e-learning platform

The Virtual Laboratory begins with one of the main laboratory room of UPB institution related to the Testing & Materials characterization (like it is shown in Figure 2.3.2).

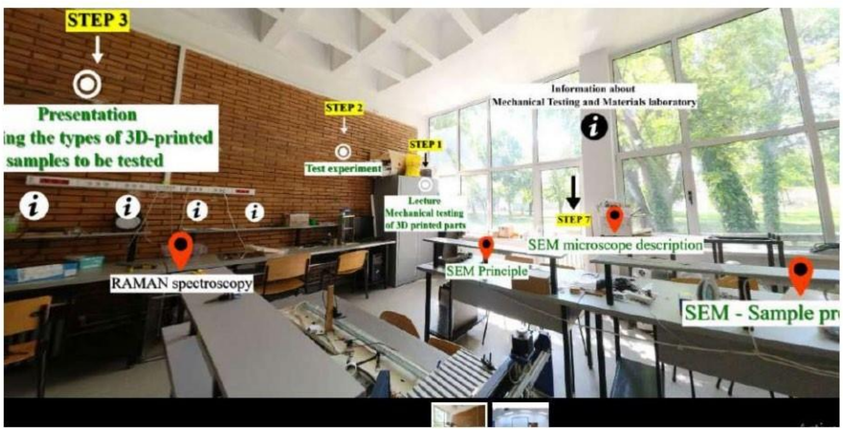

Fig.2.3.2. Testing and Materials characterization laboratory

The Testing & Materials characterization laboratory room of UPB that can be seen in Figure 2.3.2 has been realized using Insta 360 camera, the captured images undergoing in further processing using Kuula software, allowing the integration of educational materials related to the Material characterization and testing for the bio-mechatronic components that have been developed within the EMERALD project related to this topic, including mechanical testing (with the description of the main methods that are used for such testing, like tensile strength testing, compression testing, hardness, etc), continuing with different types of microscopy analyses (like SEM / TEM) or other characterizing methods (like FTIR, etc) and ending up with other additional important methods of analyses, like quality engineering (tolerances) or aspects related to the plastic aesthetics. Concerning the educational resources that are provided within the e-learning platform in relation with the

Testing & Materials virtual laboratory resources are referring mainly to the course module that has been realized by the UPB partner in the frame of O1, completed by an additional lecture that has been realized by the UPB partner within O3 concerning the Polymeric materials, referring in principle to the ones that can be processed by 3D printing technologies.

Figure 2.3.3. Examples of applications and structures realized by 3D printing technologies

In this lecture there are provided valuable information about the new types of materials that have been lately developed for the 3D printing technologies, including new types of bio-materials. Second set of information refers to different types of microscope analyses that are being explained in terms of working principles (Figure 2.3.4), settings, equipment items (types, performances, etc) so as the user can get easily familiarized with these type of equipment / instruments and the importance of the evaluating that is being realized based on microscopy and other types of analyses like X-ray, spectroscopy, etc. Information related to preparing of the samples for different types of analyses, are being provided in the laboratory.

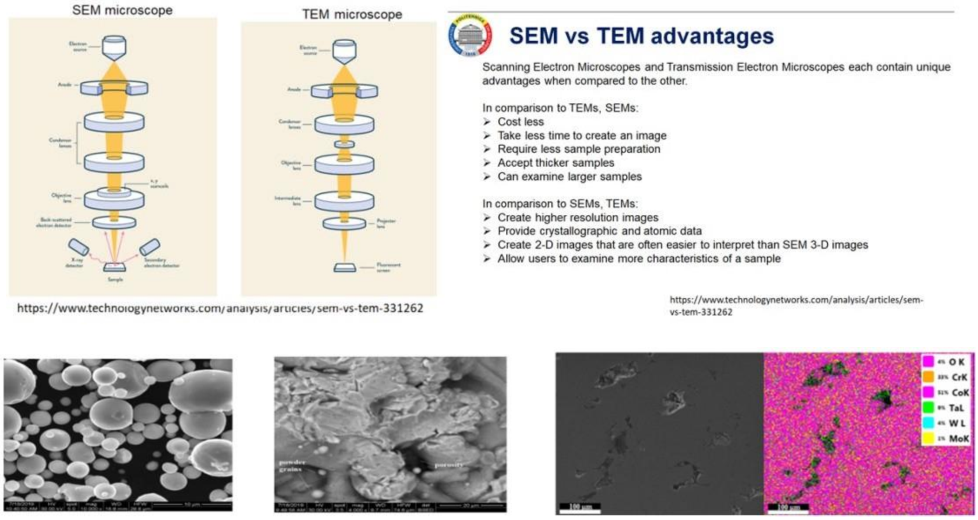

Figure 2.3.4. SEM vs TEM microscopy methods

In terms of mechanical testing one additional lecture (and presentation) has been added in the frame of O3 focusing on the presenting of different types of methods that are used for the realized testing, like Tensile strength, hardness determination, toughness tests, etc. These aspects were integrated within the room by short descriptions that have been made (while different spots in the room are being accessed by the users), by short relevant photos that are providing steps that are followed on different procedures or by videos that have been realized / filmed while different components (like a hand orthosis) has been mechanically tested.

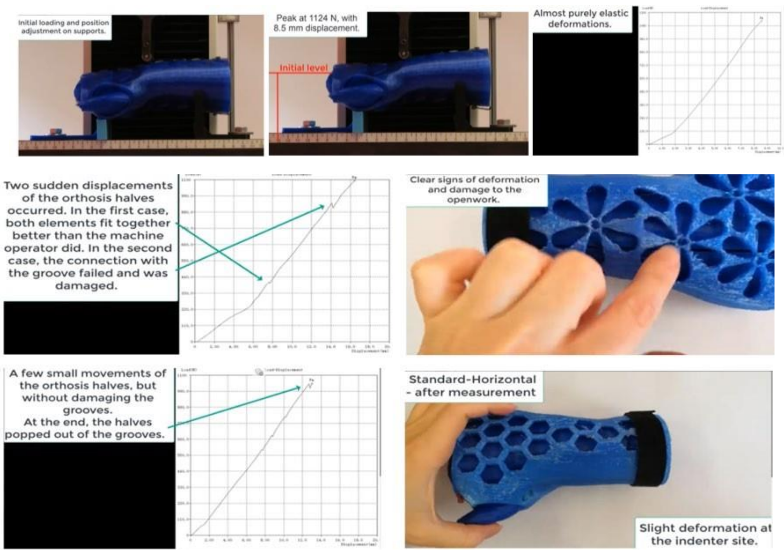

Figure 2.3.5. Mechanical testing of the orthoses

Mechanical testing of several samples made of different types of materials in order to determine the mechanical characteristics to be included in the CAE analyses for a much reliable assessment of the results in terms of CAE done not relying on data undertaken from library of the programs / catalogues from the internet are being provided also. Last, but not least, an additional lecture related to highly important aspects regarding the prescribed precision and manufacturing precision of implants, prostheses and orthoses has been prepared by the UPB partner (in the frame of O3) to emphasize the importance of quality control / quality assurance / precision and tolerances of the realized bio-mechatronic systems, aspects that come in completion to the already provided information about the Materials characteristics and testing methods (Figure 2.3.6).

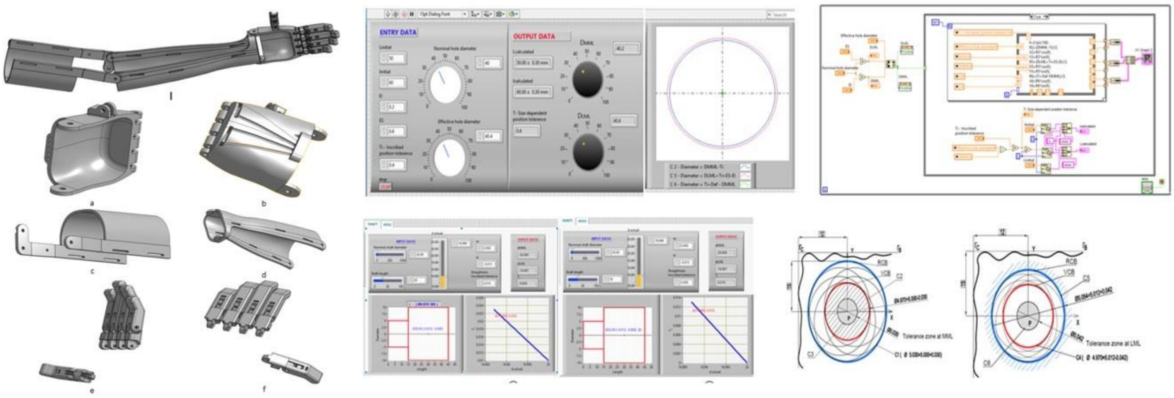

Figure 2.3.6. Precision and tolerances of the realized bio-mechatronic systems

Presentations on different other topics like Plastic aesthetics has been included in the virtual laboratory on Testing & Materials also. In this laboratory, taken into consideration the complexity of the methods and the fact that these methods are depending on the existing logistics and infrastructures existing on the physical laboratories, on the e-learning virtual laboratory platform of EMERALD were used images or videos when there have been explained practical things. For the students (users) it was important to understand the role of these methods in determining real characteristics of the testing that are being made and the importance of these determined characteristics for selecting the proper materials for certain type of bio-mechatronic components.

In order to support the students (users) with the selection of proper materials, in the toolkit manual that has been prepared in the frame of O2 and have been integrated into the e-learning platform, students (users) are being teach and can do a real practical thing by accessing the Total Materia database that is widely used for determining of the materials properties in concordance with the type of bio-mechatronic component they are aiming to realize (see Figure 2.3.7). In this way, step by step, following this tutorial students (users) are being teach how to select the proper material (from several alternatives) in concordance with the requirements of the bio-mechatronic components to be made from different types of materials (plastic, metallic, ceramic) in close correlation with the mechanical characteristics (mechanical resistance) in the end.

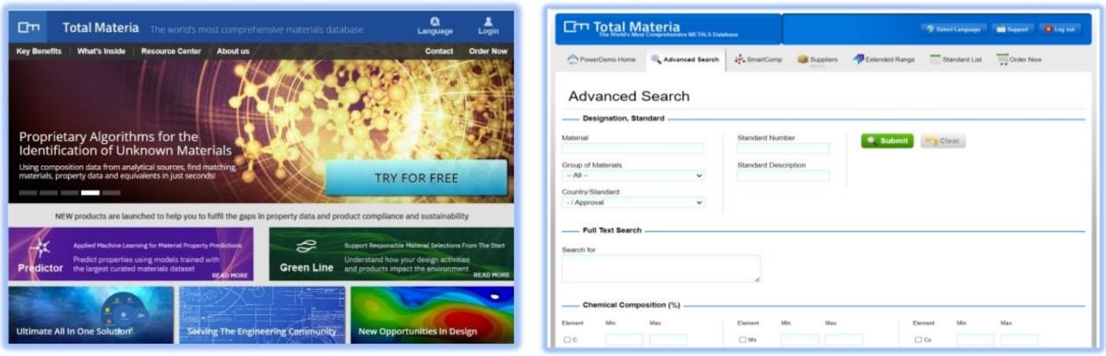

Figure 2.3.7. Total Materia database for proper selecting of the materials to be used for realizing of bio-mechatronic components using 3D printing technologies

2.4. 3D printing virtual laboratory room (PUT)

3D printing virtual laboratory room which has been assigned to the Poznan University of Technology as one may notice in Figure 2.4.1 can be accessed from the www interface of the EMERALD project (https://project-emerald.eu/?page_id=404) or directly by accessing the next following link: https://my.matterport.com/show/?m=NXHcatKcdW7&sr=-2.95,.1&ss=37

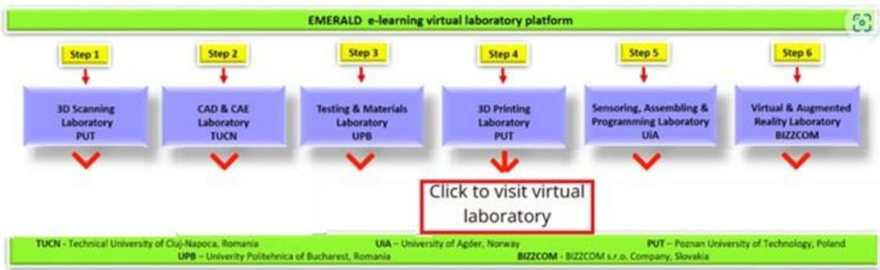

Figure 2.4.1. Accessing of the 3D printing laboratory room from the e-learning platform

If the 3D scanning laboratory is accessed first, it is still possible to travel to the other lab, as physically they are in one space (see Figure 2.4.2). The guideline for traveling to the 3D printing lab starting from 3D scanning lab is presented in Figure 2.4.3. Similarly as the 3D scanning virtual laboratory room at PUT, 3D printing laboratory, has been realized using Matterport Pro camera, the captured images undergoing in further processing using Matterport software, allowing the integration of educational materials related to 3D scanning for the bio-mechatronic components that have been developed within the EMERALD project related to this topic in particular.

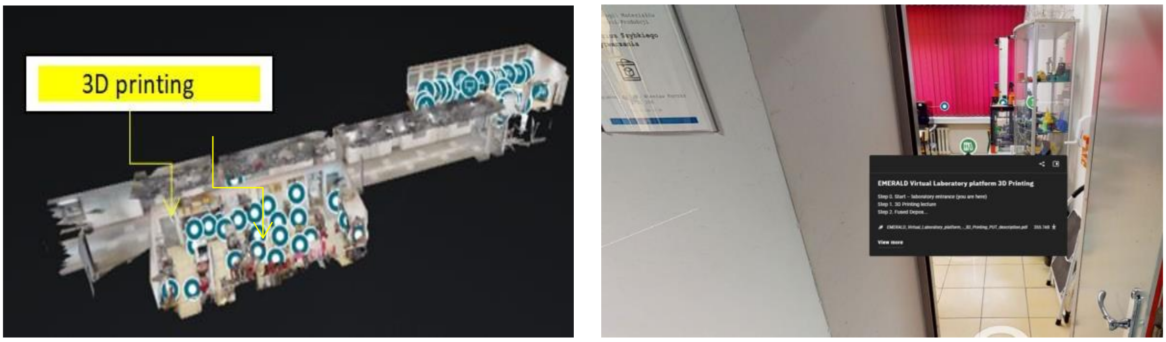

Figure 2.4.2. Main entrance of the 3D printing laboratory of PUT

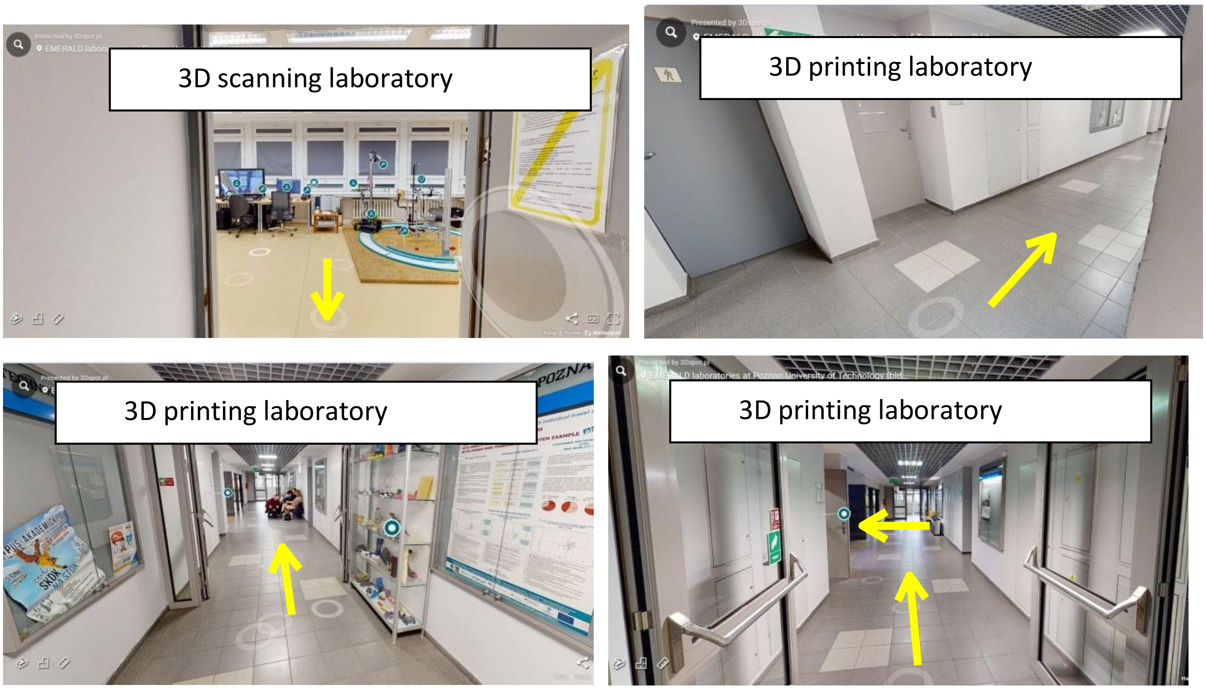

Figure 2.4.3. Reaching to the 3D printing virtual laboratory of PUT

In this Virtual Laboratory, it is possible to explore 3D printing processes of parts of biomechatronic devices created as case studies of the EMERALD project. The users can get familiarized with 3D printing techniques of polymeric materials – FDM and PolyJet technologies, then see educational videos about how different devices are manufactured. The last step is learning how to create programs for these devices, by use of video tutorial and instruction of installation and use of programs for that purpose. The course of 3D printing available in that part of PUT virtual laboratory has been divided into 6 main steps (Figure 2.4.4), with multitude of additional information available besides these steps. Users (students) are asked to explore on their own the laboratory and open everything they think could be interesting.

Steps: Step 0. Start – laboratory entrance, Step 1. 3D Printing course module and lecture, Step 2. Fused Deposition Modelling – wrist hand orthosis – tutorial video, Step 3. Fused Deposition Modelling – bicycle prosthesis gripper – tutorial video, Step 4. Fused Deposition Modelling – ankle foot orthosis – tutorial video, Step 5. PolyJet – mechatronic prosthesis gripper – tutorial video, Step 6. Tutorials on creating programs for 3D printing processes

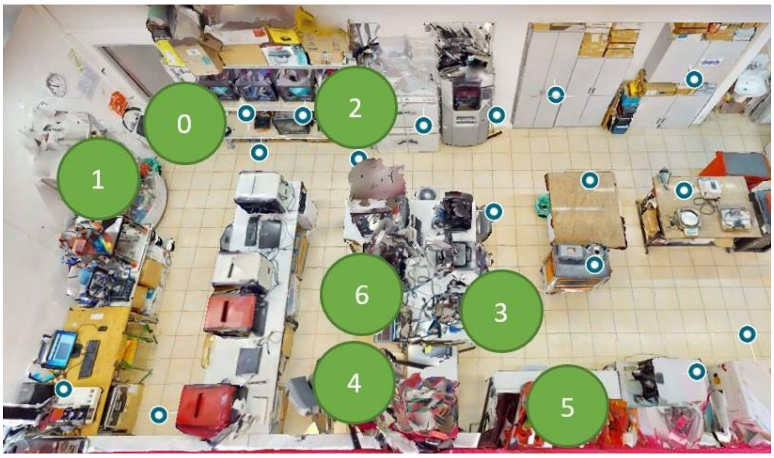

Figure 2.4.4. 3D printing – steps of the course

In Step 1 of the 3D Printing section of the EMERALD e-learning platform, students are introduced to the basics of 3D printing, particularly in the context of creating bio-mechatronic systems for individuals with special needs, such as amputated arms. This step includes foundational course materials, including an O1 course module and a lecture in slide format. The lecture focuses on the working principles of major 3D printing methods applicable to bio-mechatronic components.

The course module on 3D printing, created by partners PUT and TUCN in the EMERALD consortium, is accessible through the 3D printing laboratory of the e-learning platform. This module provides comprehensive theoretical information crucial for understanding various 3D printing technologies and their applications in biomechatronics.

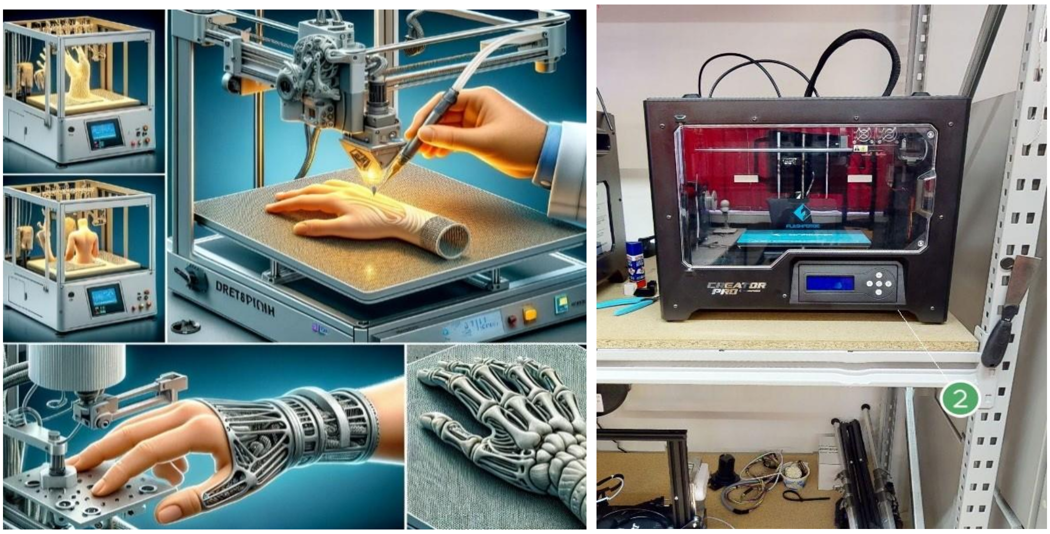

Figure 2.4.5. 3D printing technologies and their applications in biomechatronics

Key aspects covered in the module include the introduction to Additive Manufacturing (AM), 3D printing in medicine, biomechatronics, basics of 3D printing technology, a review of 3D printing technologies, preparation for 3D printing processes, examples of 3D printed biomimetic devices, and a case study on a therapeutic wrist hand orthosis. This step lays the foundation for students to understand the essentials of 3D printing, particularly in the context of designing and manufacturing bio-mechatronic components such as orthoses and prostheses.

In the EMERALD e-learning platform, Steps 2 to 5 in the 3D printing section involve watching a series of time-lapsed videos that demonstrate the 3D printing processes of various biomechatronic device parts (Figure 2.4.6). These steps provide a practical insight into the manufacturing of components related to specific EMERALD project case studies. The videos showcase the printing of different parts using a range of 3D printers and materials, offering learners an understanding of the nuances and particularities of 3D printing in the field of biomechatronics. Each video focuses on a different component and utilizes various 3D printing methods and materials, providing learners with a hands-on understanding of the 3D printing process and its applications in biomechatronics.

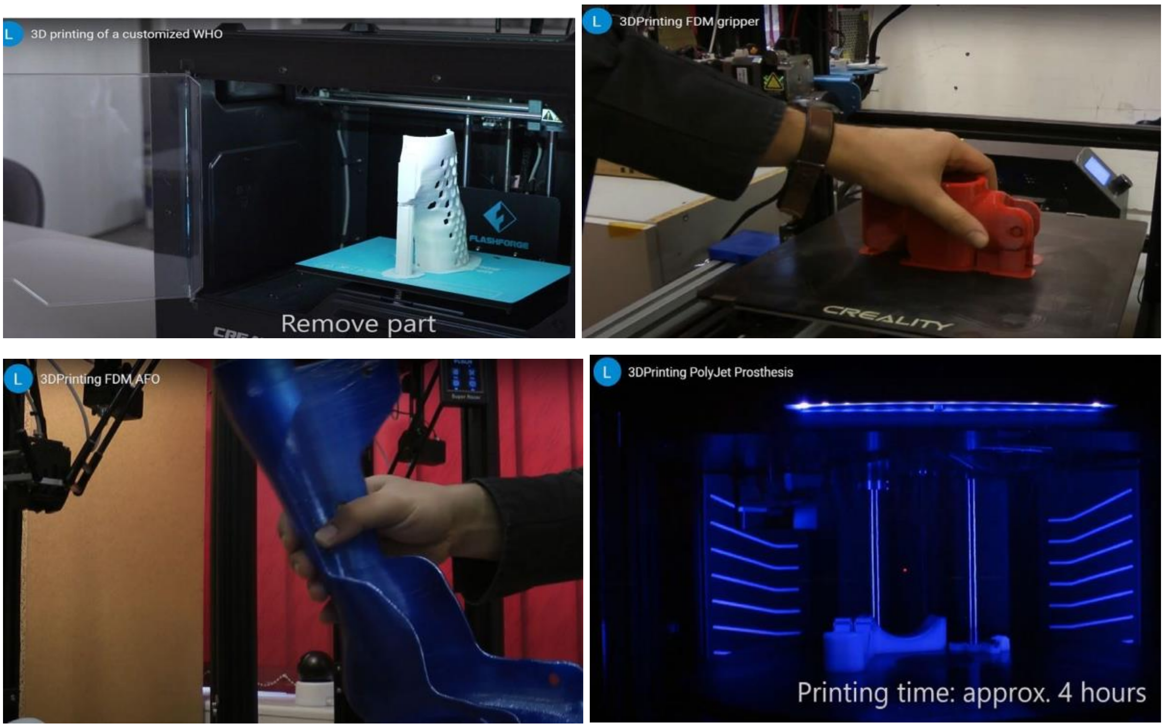

Figure 2.4.6. Video 3D printing tutorials

In Step 6 of the EMERALD e-learning platform’s 3D printing section, students at Poznan University of Technology have the opportunity to delve into the practical aspects of 3D printing software. This step offers a compound video tutorial that demonstrates the use of three different software solutions for preparing programs to manufacture parts of biomechatronic devices related to the EMERALD project's case studies. The tutorial guides students through key points to consider during the preparation process and encourages them to install the respective software and try out the processes themselves. This hands-on experience ensures that learners can grasp the complexities and subtleties of 3D printing software in the context of creating biomechatronic devices.

Figure 2.4.7. Tutorial guides for the students

In Steps 8 through 10 of the TUCN laboratory rooms, students using the e-learning platform are provided with an immersive and educational experience in the world of 3D printing. Step 8 invites students to virtually visit the 3D printing labs at TUCN, where they can explore videos demonstrating how these technologies operate and observe various applications realized at TUCN (Figure 2.4.8).

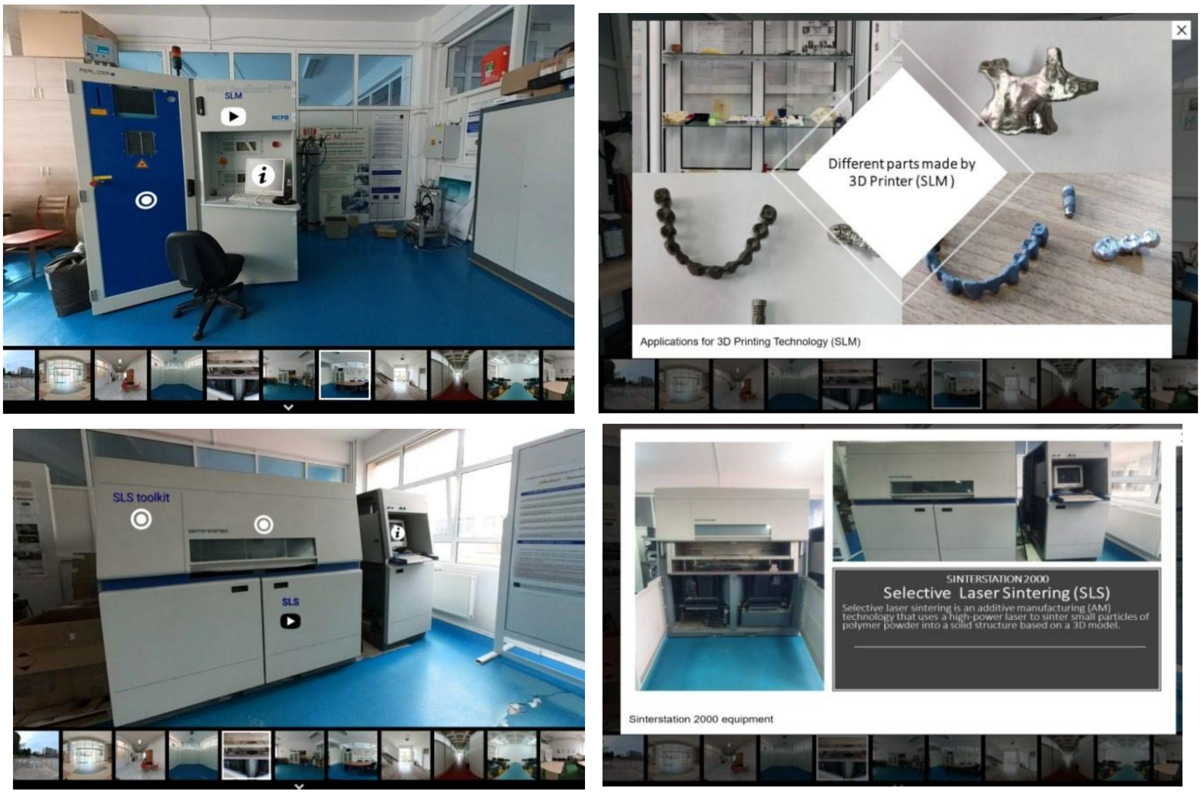

Figure 2.4.8. Lab tours of TUCN in which students can explore videos, equipment items, applications

Step 9 offers a range of tutorials and videos covering topics from preparing files for 3D printing to specific techniques and methods. Finally, Step 10 showcases good practice examples of 3D printed models by students, providing insights into their creative use of FDM printing technology.

Figure 2.4.9. Tutorials and good practice examples realized by the students

2.5. Sensoring, assembly and programming virtual laboratory room (UiA)

Sensoring, assembly and programming) virtual laboratory room which has been assigned to the University of Agder (Norway) as one may notice in Figure 2.5.1 can be accessed from the www interface of the EMERALD project (https://project-emerald.eu/?page_id=404) or directly by accessing the next following link:

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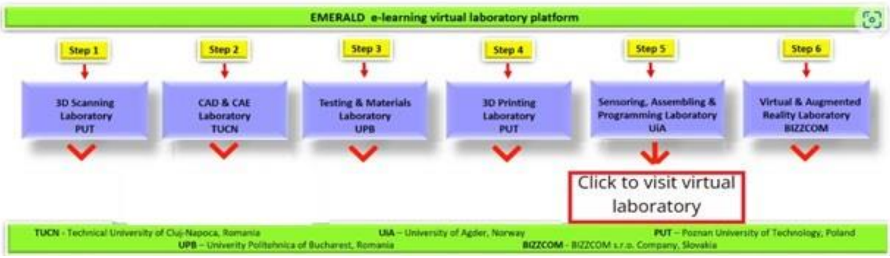


Figure 2.5.1. Accessing of the sensoring, assembly and programming virtual laboratory room from the e-learning platform

The Virtual Laboratory tour begins at the entrance of the UiA main building, as shown in Figure 2.5.2. Upon entering the building through the main corridor, one may access the sensoring, assembly and programming, as shown in Figure 2.5.3.

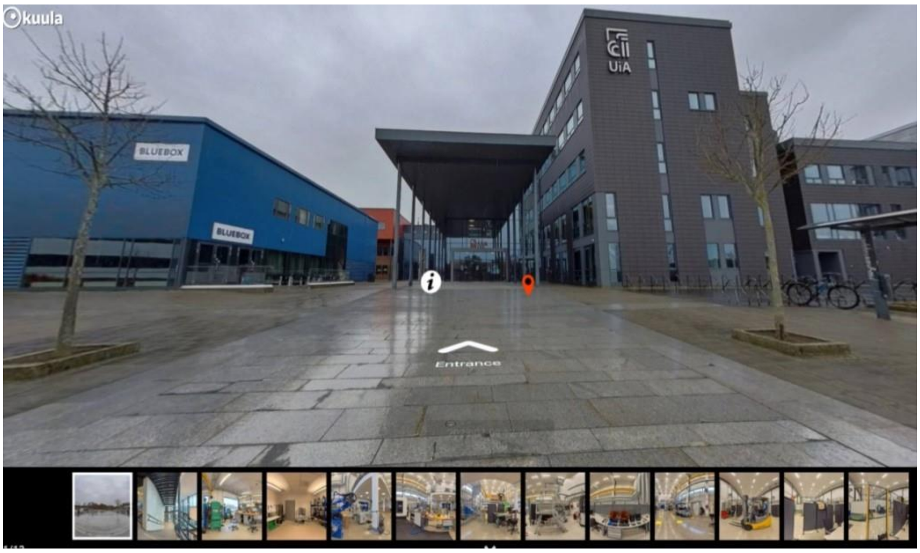


Figure 2.5.2. Entrance of the UiA main building

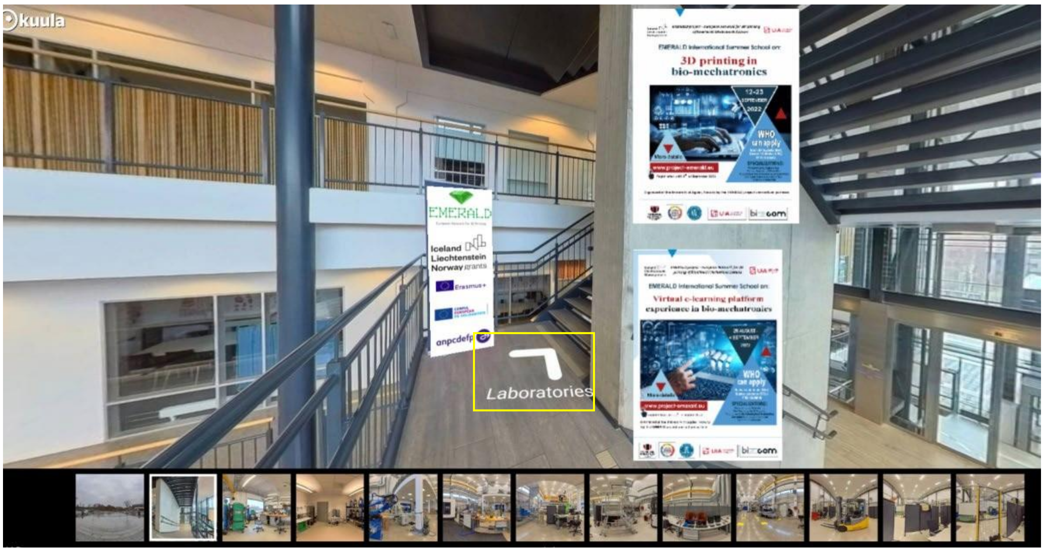


Figure 2.5.3. Access to the sensoring, assembly and programming laboratory (UiA)

The first virtual laboratories to visit at UiA which can be seen in Figure 2.5.4 have been assigned for the sensorics, actuators and for additional aspects related to bio-mechatronic.

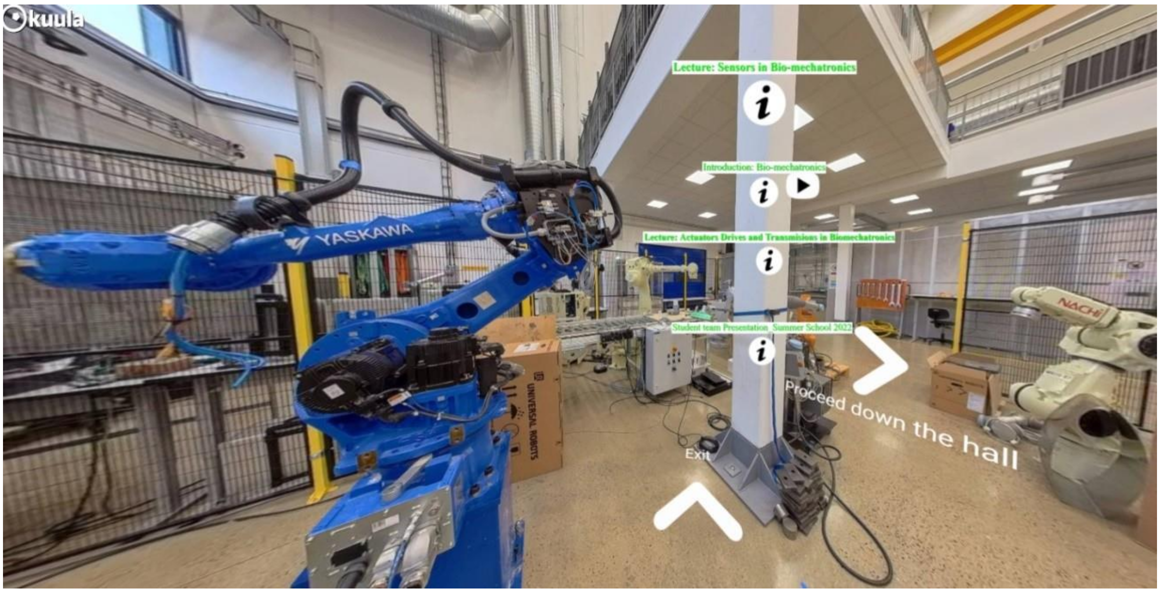
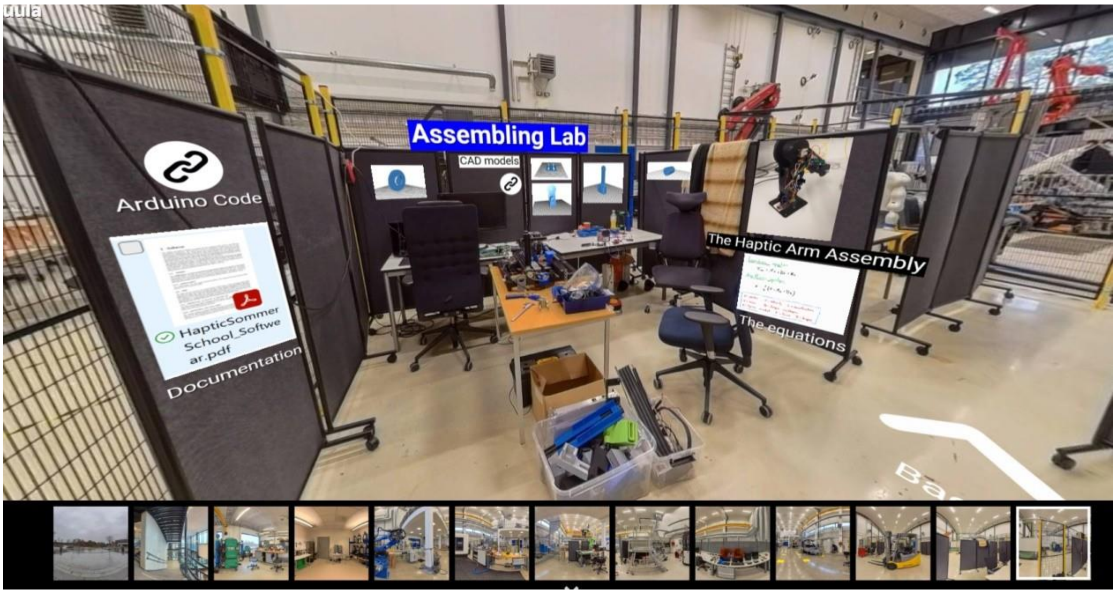


Figure 2.5.4. Virtual laboratory of sensorics, actuators and bio-mechatronics (UiA)

In same way there have been assigned specific laboratories for the Assembling and Programming topic at University of Agder (UiA) as one may notice presented in Figure 2.5.5.



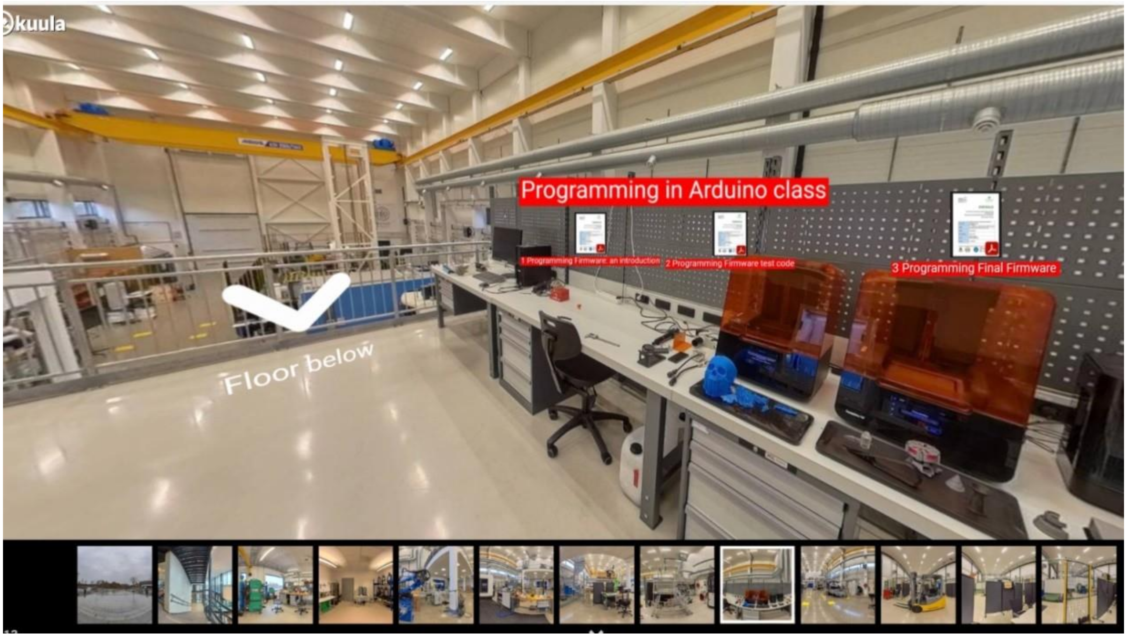


Figure 2.5.5. Assembling and programming virtual laboratories at University of Agder (UiA)

All figures that can be seen in Figures 2.5.3 to 2.5.5 have been realized using Insta 360 camera, the captured images undergoing in further processing using Kuula software, allowing the integration of educational materials related to the sensoring, assembly and programming of the bio-mechatronic components that have been developed within the EMERALD project related to these topics.

The e-learning virtual laboratory platform dedicated to the sensoring, assembly and programming stage in particular offers an enriched educational experience that is tailored to the bio-mechatronic systems destined for people with special needs (with amputated arms) such as robotic arms, orthoses and prostheses, focusing on the necessary steps that are particularly necessary to be followed after the 3D printing of the component, step that is continuing mainly with the sensoring, assembling and programming of such systems. The main aim of the platform in relation to sensoring, assembling and programming aims to familiarize the users and facilitate their comprehensive learning by providing them first the basics on types of sensors that can be used for such type of systems, followed by the assembling of other important components, like step engines or actuators and ending with the programming steps that are necessary to be realized for such type of systems. In order to comprise easier all these steps, students (users) are invited to go through some lectures / courses on the beginning so they can comprise the terminology and the basics, and to go afterwards to a set of instructional videos or applications or toolkits through which they can easily understand how sensoring, assembling and programming of such bio-mechatronic systems has to be realized in the end.

In Step 1 of the Sensoring course module in the EMERALD e-learning virtual laboratory, offered by UPB partner as part of Objective 1, students are introduced to the critical role of sensors and electronics in bio-mechatronic systems (Figure 2.5.6). This foundational step emphasizes the importance of creating a material connection with the process under observation and provides an understanding of how sensors interact with processes to provide measurable data.

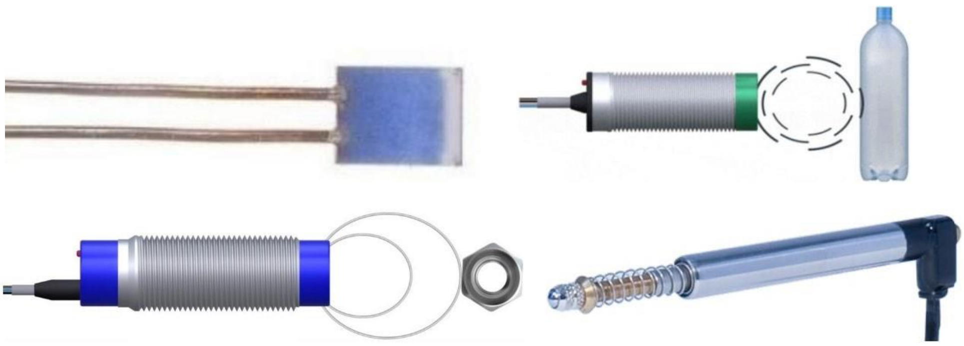


Figure 2.5.6. Different types of sensors that are used for the bio-mechatronic systems

The module then proceeds to an extensive analysis of sensors, categorizing them into parametric (passive) and generative (active) types.

Disclaimer: This results was realised with the EEA Financial Mechanism 2014-2021 financial support. Its content (text, photos, videos) does not reflect the official opinion of the Programme Operator, the National Contact Point and the Financial Mechanism Office. Responsibility for the information and views expressed therein lies entirely with the author(s).

Parametric sensors like strain gages, RTDs, and capacitive sensors are explored in detail, along with generative sensors such as accelerometers and photodiodes. This section offers comprehensive insights into sensor operations and applications.

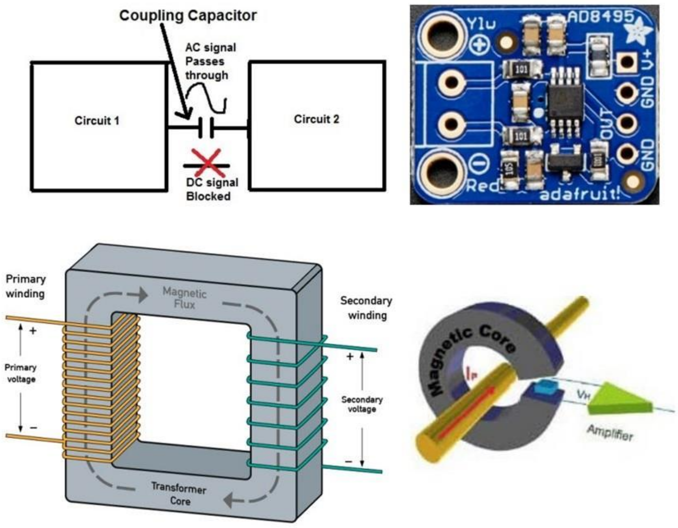


Figure 2.5.9. Other system components that is necessary to be integrated within bio-mechatronic systems

Signal conditioning is another critical aspect covered in the course, explaining how to adapt sensor output for compatibility with other system components. Operations like input coupling, filtering, amplification, and isolation are discussed in detail, accompanied by illustrative images (Figure 2.5.10).

Figure 2.5.10. Integrating of sensors and electronics into the structure of bio-mechatronic systems

The course concludes with a discussion on analog-to-digital converters (ADCs) for converting analog sensor signals into digital format for computer processing, focusing on aspects like measurement range, resolution, and scan rate. Moving on to Step 2, an additional video presentation prepared by UPB complements the theoretical knowledge with practical insights into applying sensors and electronics in bio-mechatronic systems. This video demonstrates the integration of sensors and electronics into the structure of bio-mechatronic systems, enhancing students' understanding of their applicability.

In Step 3, the University of Agder offers two comprehensive course presentations focusing on the integral roles of sensors in biomechatronics and the functionality of actuators, drives, and transmissions in biomechatronic systems. The first presentation explores the importance of position sensors in these systems, emphasizing precision, control, and safety (Figure 2.5.11). Closed-loop control systems are discussed, highlighting the role of position sensors in continuous feedback.

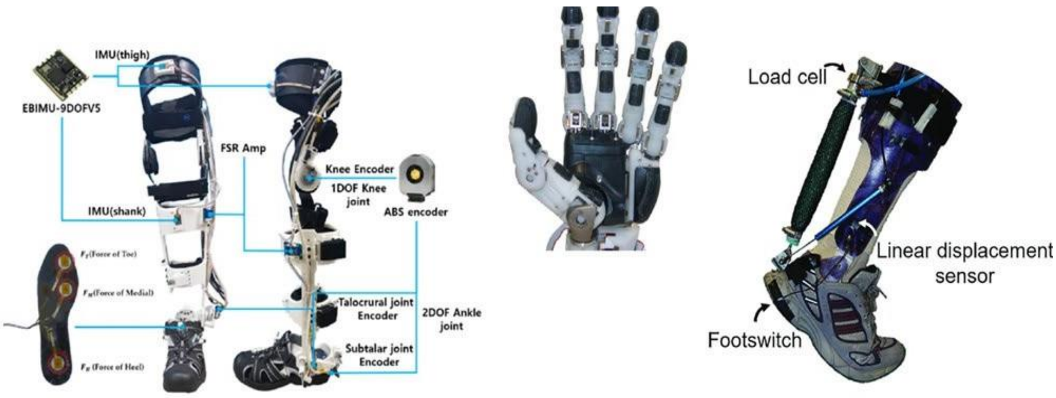


Figure 2.5.11. Practical use of positioning sensors in biomechtronics

The presentation on actuators, drives, and transmissions underscores the significance of actuators as driving forces in biomechatronic systems and the use of advanced drive systems for smooth movements. It introduces haptic feedback and telemanipulation technologies, enhancing the user experience (Figure 2.5.12). Steps 4 and 5 introduce additional lectures related to biomechatronic systems and CAD for electronic circuits. The Biomechatronics course module highlights the interdisciplinary nature of biomechatronics, showcasing advancements in the field and its applications in medical devices, prosthetics, and rehabilitation technologies. The CAD Design of Electronic Circuits module offers practical insights into PCB design, crucial for effective CAD design in electronics.

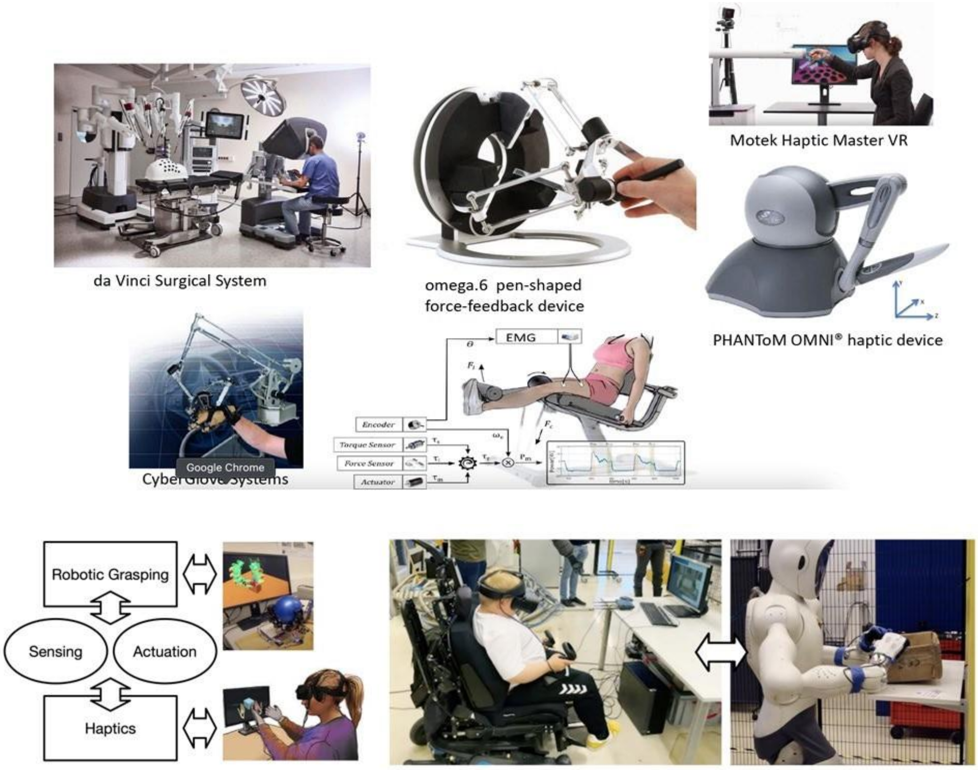


Figure 2.5.12. Sensing/actuation technology and haptic technologies used for teleoperation

In Steps 5 and 6, students engage in practical applications of assembling and programming in the realm of biomechatronics (Figure 2.5.13). Step 5 involves assembling a robotic gripper, providing documentation and interactive resources for a detailed understanding of the assembly process. Step 6 focuses on Python programming, introducing learners to Python and its fundamental concepts.

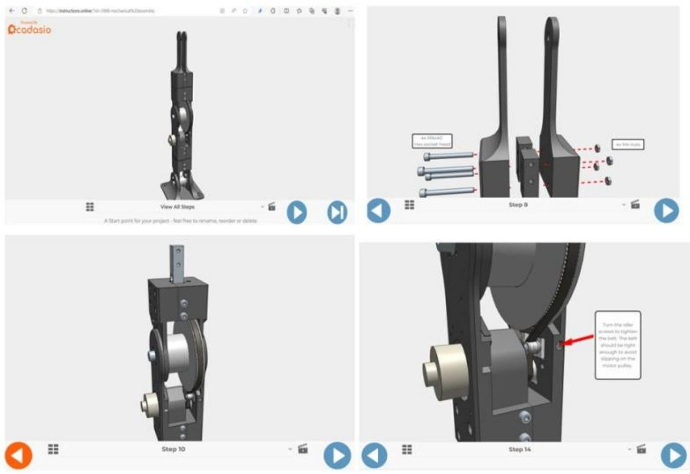


Figure 2.5.13. Robotic arm assembling application

Disclaimer: This results was realised with the EEA Financial Mechanism 2014-2021 financial support. Its content (text, photos, videos) does not reflect the official opinion of the Programme Operator, the National Contact Point and the Financial Mechanism Office. Responsibility for the information and views expressed therein lies entirely with the author(s).

Step 7 delves into Brain-Computer Interfaces (BCIs), explaining the intricate connection between the brain and computer systems. It covers neuronal communication, EEG signal analysis, referencing methods, and classification techniques. The course distinguishes between invasive and noninvasive BCIs and their applications (Figure 2.5.14).

Figure 2.5.14. Invasive and noninvasive BCIs and their applications

Steps 9 and 10 offer comprehensive resources for computer programming in biomechatronics. Step 9 provides instructions for programming firmware and acquiring MAC addresses for ESP boards. It culminates in a final test of a robotic arm. Step 10 showcases student projects and good practice examples in programming, reflecting their achievements using the educational resources provided in the e-learning platform (Figure 2.5.15).

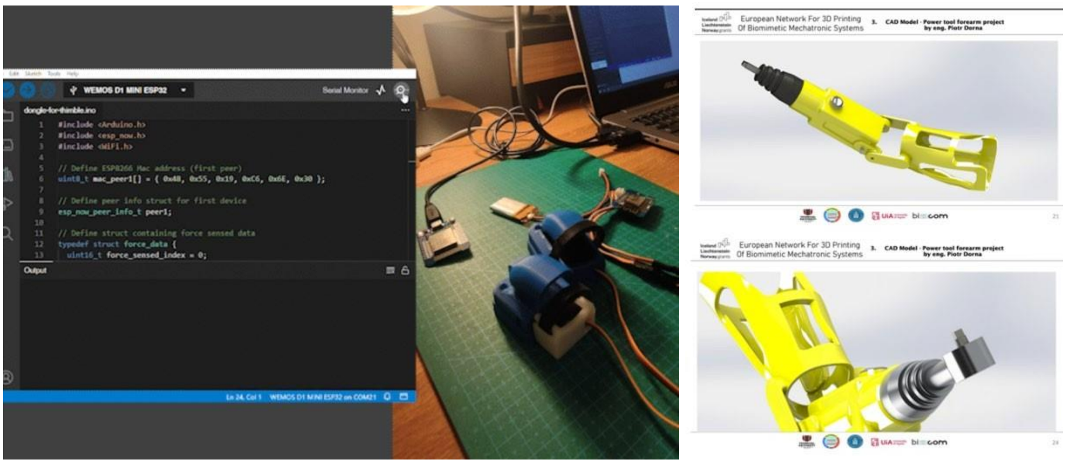


Figure 2.5.15. Student projects and good practice examples in programming

2.6. VR / AR laboratory room (BIZZCOM)

VR /AR laboratory room which has been assigned to the BIZZCOM (Slovakia) as one may notice in Figure 2.6.1 can be accessed from the www interface of the EMERALD project (https://project-emerald.eu/?page_id=404) or directly by accessing the next following link: https://bizzcom.viewin360.co/share/collection/7J4Qv?logo=0&info=0&fs=1&vr=1&sd=1&initload=0&thumbs=1

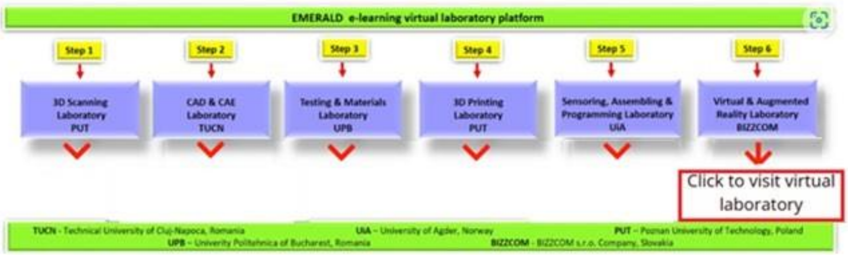


Figure 2.6.1. Accessing of the VR / AR laboratory room from the e-learning platform

The Virtual Laboratory tour begins at the entrance of the UiA main building, as shown in Figure y. Upon entering the building through the main corridor, the users are led to the engineering (training) room as shown in Figure 2.6.2 and 2.6.3.

Figure 2.6.2. Entrance of the BIZZCOM main building

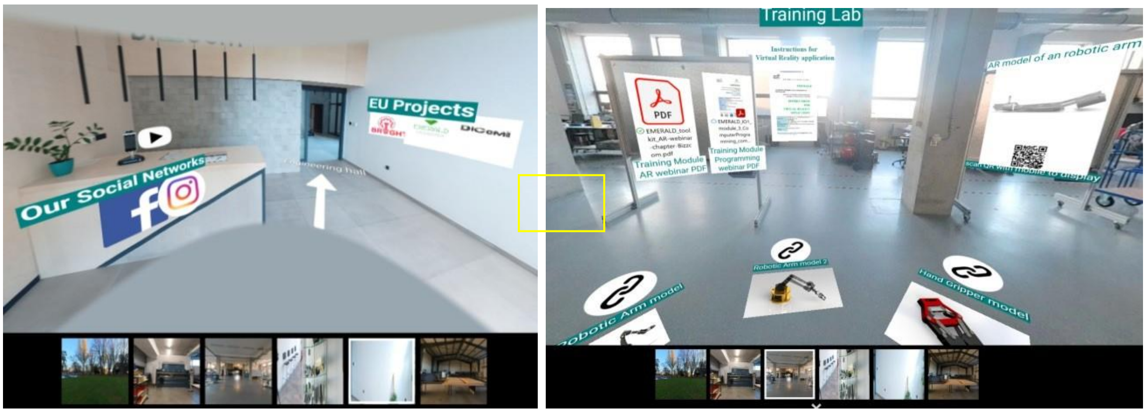


Figure 2.6.3. Access to the engineering / training laboratory (Bizzcom)

The first virtual laboratory to visit at BIZZCOM which can be seen in Figure 2.6.4 has been assigned for the AR training in principle. Room presented in Figure h has been assigned for training in VR. In this room there are provided some basics about VR, teaching resources being completed with the ones that can be found at PUT 3D scanning laboratory due to the multiple existing facilities. Beside these two rooms, there are 2 more that can be visited like: Assembling / Construction Halls, but these are just for seeing some of the existing facilities of this company (like a tour).

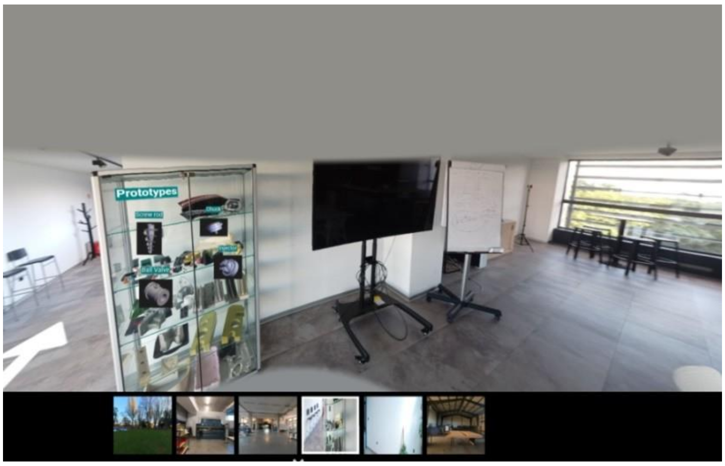


Figure 2.6.4. Training laboratory in VR (Bizzcom)

All figures that can be seen in Figures 2.6.5 have been realized using Insta 360 camera, the captured images undergoing in further processing using Kuula software, allowing the integration of educational materials related to the VR / AR of the bio-mechatronic components that have been developed within the EMERALD project related to these topics.

The e-learning virtual laboratory platform dedicated to the VR /AR stage in particular offers an enriched educational experience that is tailored to the design of bio-mechatronic systems destined for people with special needs (with amputated arms) such as robotic arms, orthoses and prostheses, focusing on the necessary steps that are particularly necessary to be followed in the field of VR/AR domain. Similar like in the case of the other virtual laboratory rooms of the e-learning platform, the VR / AR laboratory comprises a series of courses, lectures, laboratory toolkits and applications that have been realized on the EMERALD project during its period of implementation and during the organized events (international summer schools and staff for training events). In terms of VR / AR laboratory, BIZZCOM has been assigned as main responsible institution of coordinating this virtual laboratory room in particular, this institution being responsible in hosting of the staff for training event in Bucany, but the provided resources have been produced also by PUT partner who have one dedicated laboratory for VR and rest of contributions has come through the applications that have been developed by the other partners of the EMERALD consortium during the organized events.

In the initial phase of the VR/AR course module within the EMERALD e-learning program, students are introduced to the exciting realm of extended reality (XR) technologies, with a particular focus on their integration and application in the biomedical field, clarifying fundamental concepts in XR, encompassing Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). VR stands out for its capacity to craft entirely artificial environments that offer immersive user experiences. Conversely, AR enriches the real world by overlaying digital content onto the user's perspective, while MR seamlessly merges the physical and virtual domains, enabling physical and digital elements to coexist and interact in real-time.

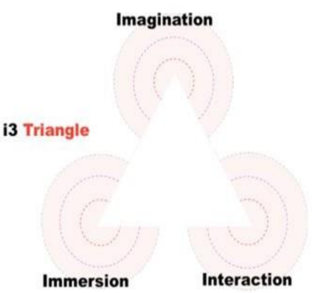


Figure 2.6.6. Main basis of VR fundamentals and immersion of users with digital scene

This module further delves into the core components of VR, including immersion, interaction, and imagination. These elements collectively shape the VR user experience, where immersion is achieved through sensory stimuli substitution, interaction involves the reciprocal influence between the user and the digital world, and imagination fills in the gaps left by technology's limitations. VR is portrayed as a unique form of human-computer interaction, characterized by its lifelike 3D graphics and intuitive user engagement. The course also covers the hardware and software components associated with XR systems, encompassing VR headsets, motion controllers, immersive gloves, and various AR/MR devices such as smart glasses and handheld gadgets. The hardware typically comprises high-performance computers, head-mounted displays, and input systems like gloves or controllers. Software includes applications and platforms for creating immersive content and enabling user interaction. Significant attention is allocated to the software aspect, particularly the utilization of 3D engines for constructing VR applications. These engines serve as comprehensive programming tools essential for developing interactive digital environments, enabling the representation of 3D geometry, object manipulation, and dynamic object interaction within applications. The applications of XR technologies are visible in diverse fields, impacting areas like engineering, education, entertainment, and medicine. The course provides examples of XR applications in medical training and patient care, including a wheelchair configurator for product visualization and VR therapy for acrophobia treatment (Figure 2.6.7).

Figure 2.6.7. Good practice examples of using VR for medical applications

In the EMERALD e-learning program, the AR programming laboratory module, developed by BIZZCOM partner under O2, provides also a comprehensive guide for creating AR applications. This module seamlessly integrates with the virtual laboratory platform and offers a comprehensive approach to AR model creation, from initial 3D object acquisition to final web publication. The process initiates with the acquisition of 3D models, achieved either through 3D scanning or by employing CAD software like SolidWorks. This foundational step is crucial for building the foundation of the AR application. Subsequently, the next phase involves optimizing and animating the 3D models for effective utilization in AR. Blender, a specialized software program, is recommended for these tasks. It enables the uploading, optimization, material/color assignment, and manipulation of model components. Animating in Blender entails setting timelines, maneuvering the object through various axes, fixing the model position at distinct frames, and making necessary adjustments. Once animations are crafted, they are saved and exported in suitable formats (Glb for Android or USDZ for iOS) to ensure cross-platform compatibility. The process then transitions to the presentation of AR models through web interfaces such as WEB APP - 3D Viewer. This interface generates previews of the 3D models using HTML code, facilitating interactive model visualization on both Android and iOS devices. Moreover, an additional presentation by BIZZCOM concentrates on further intricacies of AR application development, including web application code generation. This presentation offers comprehensive insights into crafting web application codes, generating QR codes, and viewing applications on tablets. It showcases various AR applications, including medical applications developed under O3 of the EMERALD project. In the program's fourth step, an AR library housing medical applications is incorporated into the VR/AR laboratory of the e-learning platform. This library provides an array of AR applications accessible through provided links or QR codes, enabling direct visualization on tablets (Figure 2.6.8).

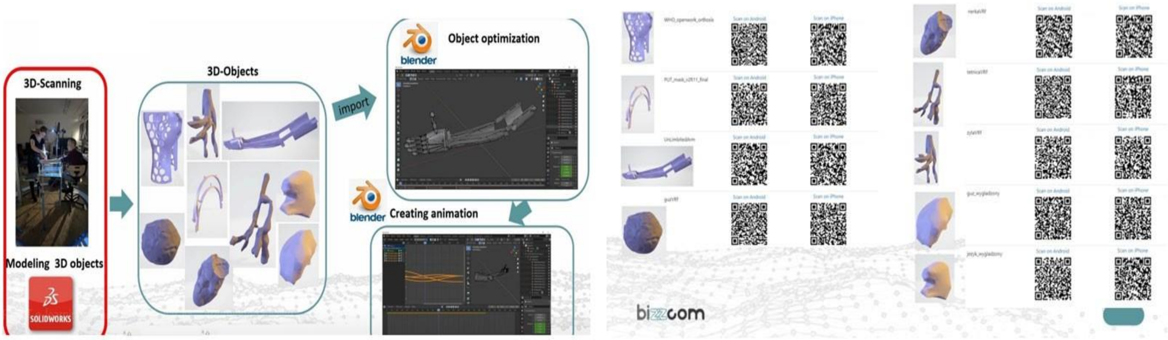


Figure 2.6.8. Examples of AR applications created using the e-learning platform resources

In Step 5 of the EMERALD e-learning program, additional resources concentrate on constructing virtual laboratories, expanding the educational arsenal with a seminar on processing 360 photos to craft VR images using Kuula software. This seminar, devised by BIZZCOM as part of O3, delivers detailed guidance on harnessing Kuula to establish an immersive platform for virtual laboratories, a practice embraced by several EMERALD consortium partners (Figure 2.6.9).

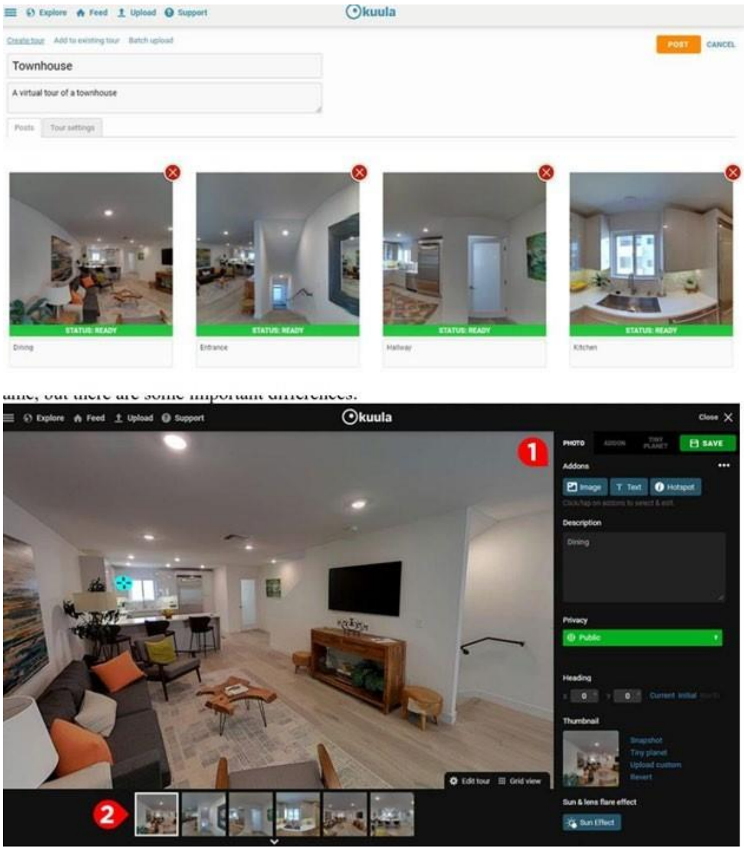


Figure 2.6.9. Seminar on realizing of virtual laboratories in Kuula software

The seminar goes deeper into tour customization in Kuula. Users are guided on incorporating comprehensive information into specific scene elements, including external website links or multimedia content. Customization extends to animated transitions between images, offering diverse options like crossfade, walk-in, and radial fade, each imparting a unique visual effect. These transitions inject dynamism into the tour, rendering it more engaging for viewers.

Another important aspect in the VR / AR laboratory of the e-learning platform is related to the Introduction in VR lecture on Matlab Simulink application (Figure 2.6.10). The lecture takes students through the process of designing a robotic arm using SolidWorks software, emphasizing attention to detail and maintaining real-world dimensions. The components are meticulously modeled and assembled in SolidWorks, including rotation couplings crucial for the robot's operation. The CAD model is then exported to Matlab/SIMULINK for dynamic simulation, ensuring compatibility.

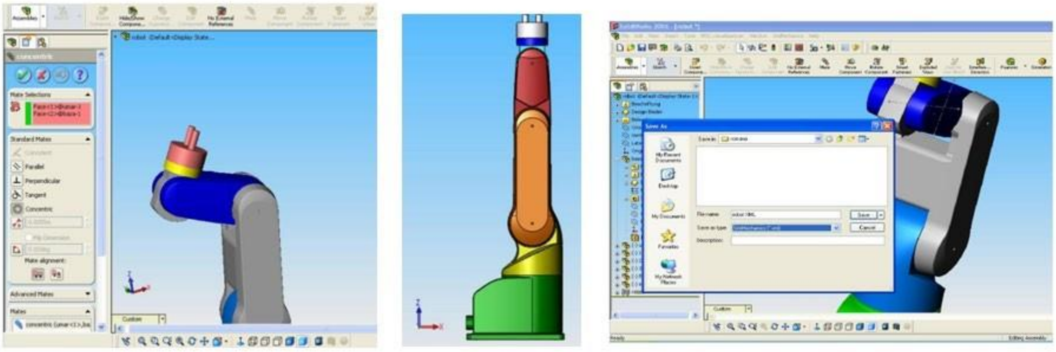


Figure 2.6.10. CAD modeling of the components of a robotic arm using SolidWorks program

In Matlab, each element of the robot is associated with specific objects in Simulink, considering environmental factors. The SimMechanics model is created using the Virtual Reality Toolbox module, enhancing the VR environment. The model undergoes modifications in VRealm Builder, introducing transformation points, light sources, backgrounds, and viewpoints for realism. The dynamic model in Simulink is modified, attaching robotic elements to a central coordinate system. Sensors provide output signals for positions and orientations, connected to the VR module. Actuators control torque, and a joystick is used for position control, with a PID controller for precise motor control. Interactive force feedback using a joystick offers realistic simulation and control of the robotic arm (Figure 2.6.11).

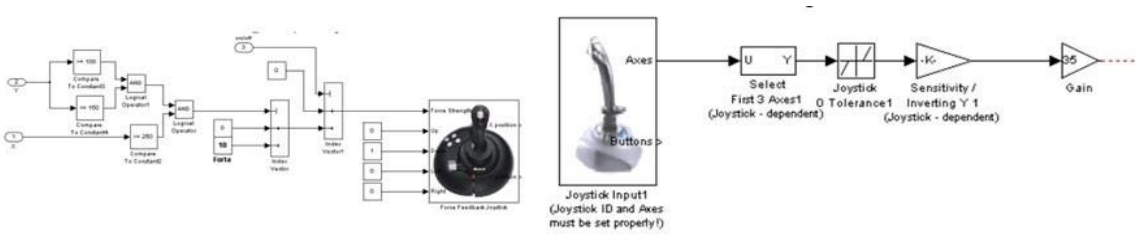


Figure 2.6.11. Force feedback generation diagram and generating position signals by the Joystick

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In Step 7 of the EMERALD e-learning program, TUCN has developed a presentation focused on creating VR applications using GLTF mode, integrated into the VR/AR laboratory of the e-learning platform. This presentation offers a deep dive into the process and technologies for creating 3D assets and their applications in virtual reality environments. It highlights Sketchfab as a source for 3D assets and references VR Home on Oculus, demonstrating the practical application of these assets in VR settings. The presentation emphasizes the importance of file formats suitable for VR applications, particularly recommending GLB files. GLB files, optimized through the glTF (GL Transmission Format) and STL (Stereolithography) formats, are essential for efficiently transmitting and loading 3D scenes and models in VR applications. glTF format is recognized for its ability to minimize the size of 3D assets and the processing required to unpack and use them, facilitating interoperable use of 3D content across the industry. Software tools like Paint 3D and SOLIDWORKS are noted for their capability to export or import STL files, aiding in the creation of GLB files from STL files for VR applications. Examples of VR applications created using this process by TUCN are showcased, with a full library of models available in the VR/AR laboratory of the e-learning platform. This comprehensive collection can be accessed and downloaded, offering a wide array of models for VR visualization (see Figure 2.6.12).

Figure 2.6.12. Sketchfab as a source for 3D assets and references VR Home on Oculus

Step 8 presents good practice examples of VR applications developed by students, with contributions and feedback from BIZZCOM. These applications, integrated into the VR/AR laboratory room of the e-learning platform, demonstrate the practical application of educational resources provided on the platform, as well as the utility of the provided information in building VR applications utilizing Matlab Simulink application (Figure 2.6.13).

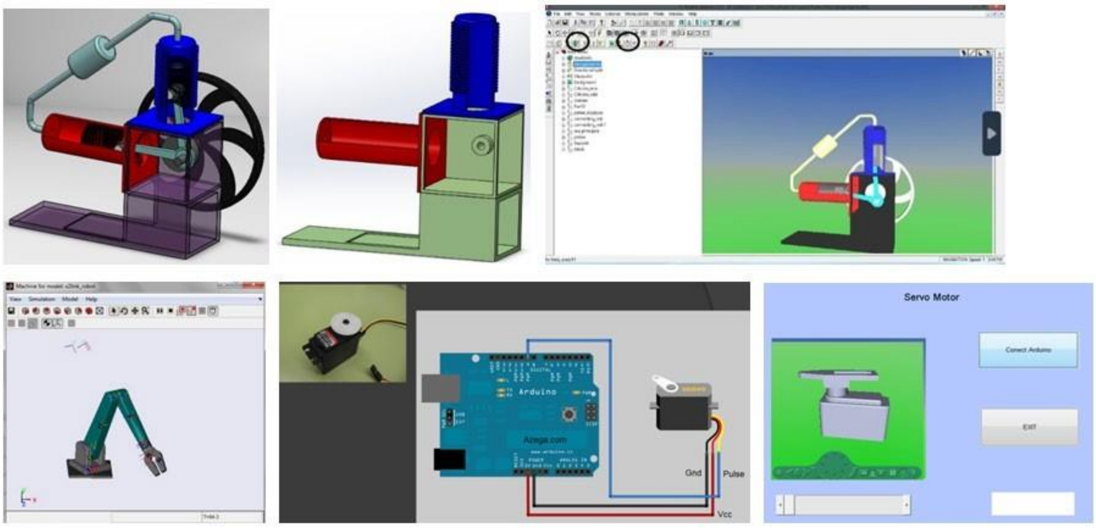

Figure 2.6.13. Examples of VR applications realized by students in MATLAB Simulink

Step 10 invites users to explore the VR laboratory room of BIZZCOM, offering a teleportation experience to the VR lab at PUT partner. This room, also serving as the 3D scanning virtual laboratory, can be accessed through the EMERALD project website or directly via a provided link. This access offers users an extensive exploration of XR and 3D scanning resources, enriching their learning experience. XR virtual laboratory room is the same room as 3D scanning virtual laboratory, so it can be accessed using EMERALD project website (Figure 2.6.14).

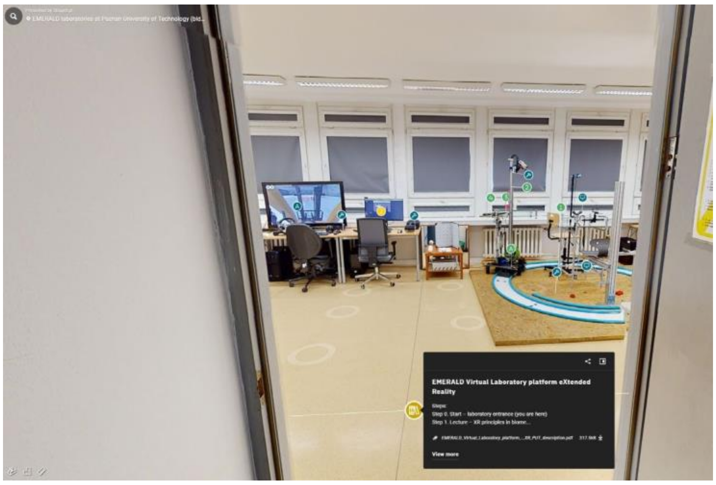

Figure 2.6.14. Main entrance of the XR laboratory of PUT

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The 3D scanning virtual laboratory room at PUT that can be seen in Figure 2.6.14 has been realized using Matterport Pro camera, the captured images undergoing in further processing using Matterport software, allowing the integration of educational materials related to Virtual, Augmented and Mixed Reality that have been developed within the EMERALD project related to this topic in particular. The VR/AR/MR applications and tutorials available here are different than the ones available at Bizzcom – they are directly related to EMERALD case studies. The course is also shorter, but more practical. In this Virtual Laboratory, it is possible to explore possibilities of building XR applications for development and use of customized biomechatronic devices (case studies of the EMERALD project). The users can get familiarized with XR techniques – virtual, augmented and mixed reality, as well as various equipment available in the laboratory. Then, for each of 3 XR techniques, a separate instruction tutorial with materials to create applications in Unity engine is made available.

The course of XR available in the laboratory has been divided into 4 main steps (Figure 2.6.15), with some additional information available besides these steps, as following: Step 0. Start – laboratory entrance, Step 1. Lecture – XR principles in biomechatronic devices, Step 2. Augmented Reality application tutorial, Step 3. Mixed Reality application tutorial, Step 4. Virtual Reality application tutorial

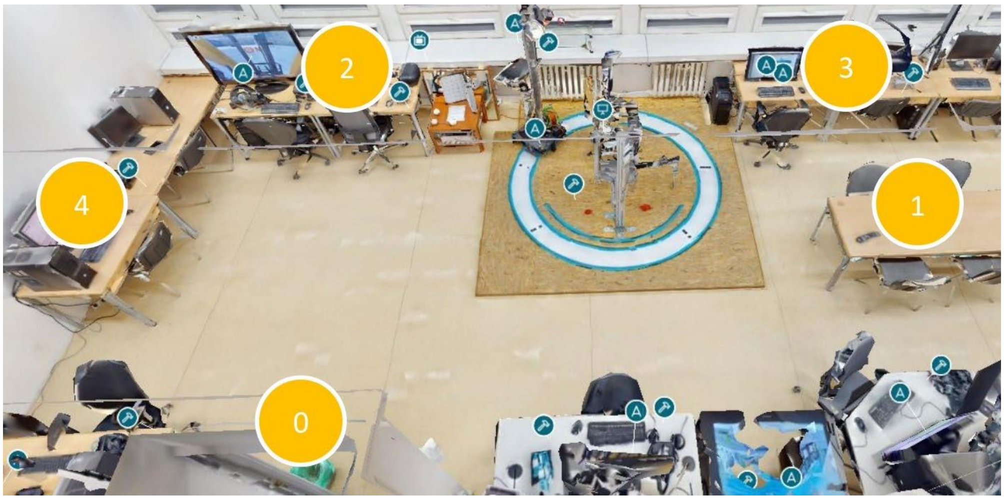

Figure 2.6.15. XR at PUT – steps of the course

Step 0, accessible right after entering the laboratory (yellow marker), contains overview of all the other steps and a short document with information for the Virtual Laboratory user.

The EMERALD e-learning platform offers a comprehensive course on Extended Reality (XR) technologies in biomechatronic device development. It covers Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), providing an in-depth understanding. The module begins by defining VR as an immersive digital 3D world, contrasting it with AR and MR. It explores XR terminology and the spectrum of XR technologies, from real to virtual environments. The course goes deeper into XR applications in engineering and medicine, including design, assembly, training simulations, therapy, and surgery training. Virtual Prototyping (VP) is highlighted. It details the process of creating virtual products, classifies XR applications by knowledge level, and discusses the lifecycle of XR applications. Practical steps in building XR applications are outlined, from planning to verification. Case studies on AutoMedPrint and VR-aided rehabilitation demonstrate real-world XR impact (Figure 2.6.16).

Figure 2.6.16. VR applications - virtual fit of a bicycle prosthesis and therapy game with use of biomechatronic orthosis

At PUT, the second step in the EMERALD e-learning program focuses on an Augmented Reality (AR) tutorial, designed as an introductory laboratory work for students, including those new to the Unity engine. The tutorial, accessible on the XR virtual laboratory of the e-learning platform, provides a step-by-step guide to creating an AR configurator for a prosthesis using Unity 3D and Vuforia Engine, aimed at Android devices like tablets, smartphones, or smart glasses. The tutorial starts with an introduction to essential tools, Unity and Vuforia Engine, for AR app development. Students create a Unity project (ARExercise) with attention to Android app folder setup. Tasks include preparing the project, importing a 3D prosthesis model, setting up an Image Target for marker-based 3D display, adding color change and animations, and creating an interactive 3D AR interface for prosthesis component selection (Figure 2.6.17).

Figure 2.6.17.AR tutorial and application

Step 3 introduces a Mixed Reality (MR) tutorial for students with basic Unity engine experience. Using Unity 3D and Microsoft's Mixed Reality Toolkit, this tutorial targets Meta Quest VR goggles with passthrough view capability (Figure 2.6.18). The first task guides students in setting up the Unity project for MR, including file extraction and project opening. The scene offers test interaction objects for user movement and hand interaction in Unity Editor. Task two involves importing 3D models, creating folders for organization, and adding the prosthesis FBX model with a 3D printed material. Task three adds configuration options, including a PressableRoundButton prefab and variant selection functionality. Task four introduces manipulation and animations to the prosthesis, adjusting the Box Collider.

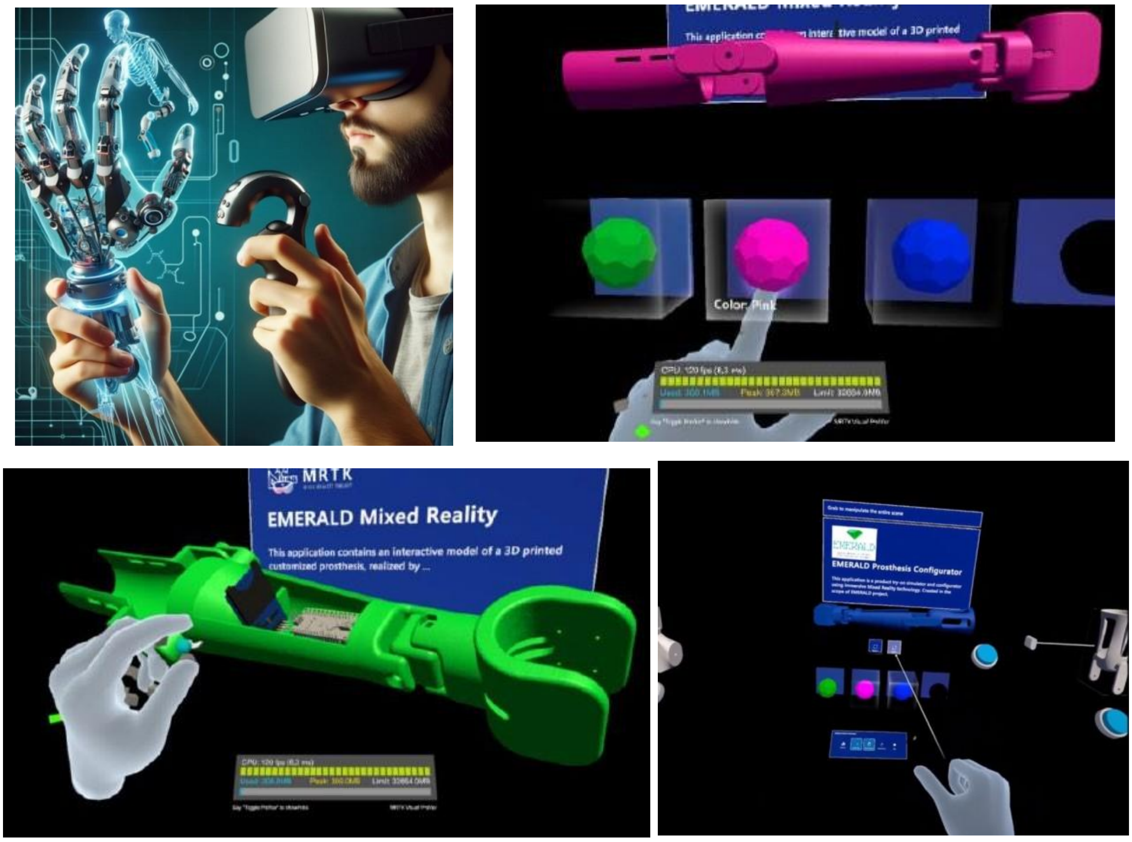

Figure 2.6.18.Mixed reality tutorial and application

At Poznan University of Technology (PUT), the final tutorial in the EMERALD e-learning program is a comprehensive Virtual Reality (VR) application tutorial (Figure 2.6.19). Oriented for students with basic Unity engine experience this tutorial guide users in creating a VR application for biomechatronic device assembly using Unity 2019.4 and the SteamVR package. The project's objective is to build an immersive VR app for assembling either a bicycle prosthesis with sensors or a therapeutic hand orthosis. It leverages Unity engine (version 2019.4.24 or higher), PC-mode VR goggles, and SteamVR. Exclusive scripts and 3D models from PUT's Virtual Design Laboratory, dedicated to EMERALD project education, are utilized. The tutorial begins with setting up a new Unity project named "EMERALD_VRExercise" and provides instructions for installing essential Unity packages, including the SteamVR plugin. The environment is configured with 3D models, such as the prosthesis/orthosis and a doctor's office setting, with the prosthesis model receiving a realistic 3D printed material texture. The core of the tutorial focuses on creating an interactive assembly process, allowing prosthesis/orthosis parts to be manipulated and locked in place upon correct assembly.

Text hints are incorporated to display part names, and an interactive 3D help button guides users through assembly. The final step involves compiling the application into an executable format, with testing using VR goggles to ensure correct functionality. A supplementary YouTube video showcases the app in action, and the executable version is available for download, enabling users to try it independently.

Figure 2.6.19.Virtual reality tutorial and application

In addition to the tutorial, the VR laboratory at PUT contains other VR materials related to the EMERALD project. These include an interactive VR tutorial application focusing on the AutoMedPrint system, a best practices presentation example by a student at PUT, and a description of the operation of various Mixed Reality goggles. These materials offer additional insights into the application of VR in therapy and the development of biomechatronic devices (Figure 2.6.20).

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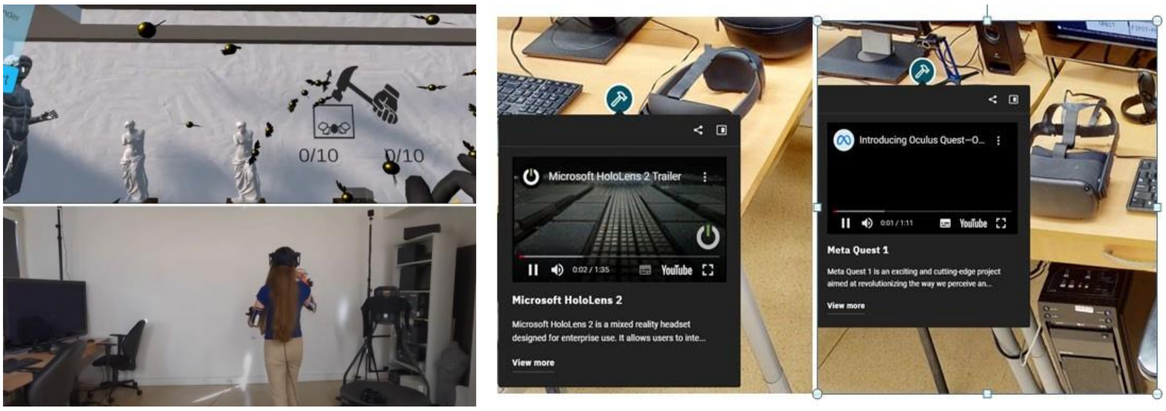

Figure 2.6.20. Additional resources in virtual laboratory of PUT related to VR, AR, and MR

In conclusion, the VR/AR teaching resources on the e-learning platform provide a comprehensive learning experience for students interested in VR application development, specifically in the context of biomechatronic devices. The detailed tutorials, along with the expertise of the authors from PUT, offer a unique opportunity to learn about VR application building using the Unity Engine. This course is a standout offering in e-learning, providing both theoretical and practical insights into the cutting-edge technologies of VR, AR, and MR.

3. Conclusions

The EMERALD consortium's has managed to realize an e-learning virtual laboratory platform that represents a remarkable stride forward in the field of biomechatronics, with a particular focus on providing teaching resources to anyone who is interested to get knowledge and skills in realizing bio-mechatronic systems to support people with special needs (with amputated arms) by using 3D printing technologies. The e-learning virtual laboratory platform distinguishes itself through its exceptional accessibility and user- friendliness, delivering an educational experience providing users with a lifelike laboratory encounter, immersing them in an environment that feels tangible, friendly and physical. Beyond being a virtual space, it evolves into a complete educational ecosystem. Within this ecosystem, each digital room, accessible in VR mode, addresses distinct phases of biomechatronic system development, offering a wide set of educational resources.

These resources comprise VR and AR applications particularly designed to provide a deeper understanding on the complexity of biomechatronic system components, practical utilities for VR/AR programming, and 3D printing equipment items used for the manufacturing process of the bio-mechatronic systems. Furthermore, the e-learning virtual laboratory platform extends its offerings to include links to instructive videos, course modules, toolkit manual, and freely available CAD, CAE, and 3D printing software, thus contributing to the learning journey of users who are accessing the e-learning platform for teaching purposes. The EMERALD e-learning platform offers e-library resources, housing CAD/CAE models and VR/AR applications available for download and hands-on exploration. These resources are highly important in the learning process, since they are linked with the information provided in the e-toolkit manual (laboratories), being possible to be replicated by 3D printing methods, by following the guides, tutorials and instructional videos that are freely accessible on the e-learning platform. Many of the provided VR/AR applications have originated from collaborative efforts between professors and students of the EMERALD consortium during diverse learning and teaching events (staff for training training event held in Bucany and the international summer school held at the University of Agder in 2023). The impact of the EMERALD e-learning platform has been consistent in particular during the organized events, on which students were actively engaged with and tested the e-learning platform, providing invaluable feedbacks to the professors of the EMERALD consortium who have been working for the conceiving and realizing of the teaching resources for the EMERALD e-learning virtual laboratory platform. The feedbacks received from the students has finally led to significant improvements in the e-learning virtual laboratory platform's scientific and educational materials resources. Furthermore, additional presentations, courses, and applications were integrated into the e-learning virtual laboratory platform of EMERALD to meet the requirements of the users that have been accessing the platform. In conclusion, the e-learning virtual laboratory platform, with its extensive and easily accessible resources aims to serve as a starting point for future stakeholders that are interested on 3D printing solutions for realizing of customized biomechatronic systems for people with amputated arms to be made on a larger scale in the end.