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EUROPEAN NETWORK FOR 3D PRINTING OF BIOMIMETIC MECHATRONIC SYSTEMS

INTELLECTUAL OUTPUT O1 - EMERALD REPORT

Project Title	**European network for 3D printing of biomimetic mechatronic systems 21-COP-0019**
Output	**O1 - EMERALD e-book for developing of biomimetic mechatronic systems**
Date of Delivery	**2023**
Authors	**All partners**

Content

1. Introduction, objectives and tasks of O1

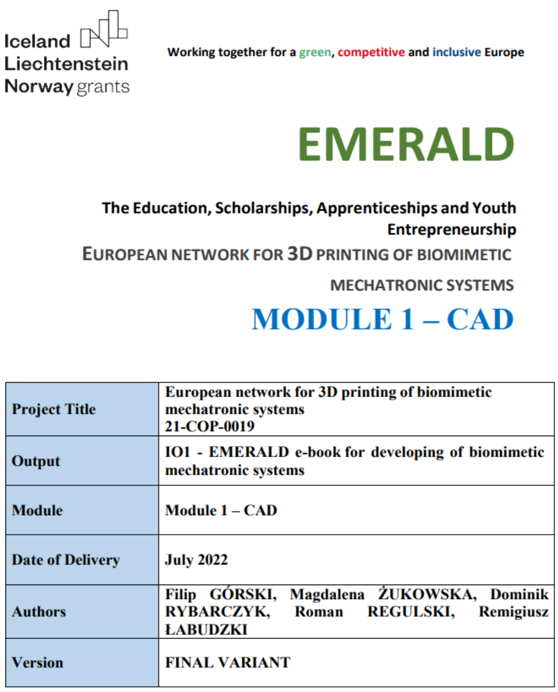
"The EMERALD project is an innovative educational initiative that joins Bio-Mechatronics and 3D Printing together, focusing mainly on creating a set of educational methods and tools to anyone interested in getting the right knowledge and expertise in conceiving, realizing and testing of bio-mechatronic systems for people with special needs (patients with amputated arms) in the end. The Technical University of Cluj-Napoca (leading institution of the EMERALD project) has played a highly important role in coordinating the development of eight comprehensive course modules that have been conceived in the frame of O1 by all the EMERALD partners of the consortium. Each partner within the EMERALD consortium brought unique and valuable expertise to the project, contributing to the rich content of the courses. Even though there were some adjustments in responsibilities from the initial plan, the scientific content of each module remained robust, focused and consistent with the initial proposal. Notably, Poznan University of Technology (PUT) took the lead on the Computer Aided Design (CAD) module, highlighting specific software and methods for designing bio-mechatronic systems. The Computer Aided Engineering (CAE) module, focusing on finite element analysis for validating CAD solutions was developed by the Technical University of Cluj-Napoca (TUCN). Computer Programming, initially a collaborative effort between the University of Agder (UiA) and BIZZCOM, was later led predominantly by BIZZCOM, emphasizing programming solutions for bio-mechatronic systems. The Virtual Reality/Augmented Reality (VR/AR) module was realized with high responsibility by PUT and BIZZCOM, taking into consideration their extensive experience in VR/AR applications. The University Politehnica Bucharest (UPB) has been responsible in producing the Sensors & Electronics course and the Intelligent Materials course. The 3D Printing & Rapid Tooling methods module was assigned to PUT, given their ongoing research and advancements in creating orthoses and prostheses using 3D printing technologies. The bio-mechatronic course was undertaken by the University of Agder, owing to their significant experience in developing and testing robotic systems. UiA's expertise was instrumental not only in developing this course but also in providing valuable feedback across all modules. Each course module was carefully designed to impart essential knowledge for customizing bio-mechatronic systems to meet the specific needs of people with amputated arms. These modules, available with open access on the EMERALD project website (see: https://project-emerald.eu/?p=262), are a testament to the collaborative effort and commitment of the consortium partners in advancing the fields of bio-mechatronics and 3D printing for practical, life-changing applications in the end.

2. EMERALD course modules

As it was mentioned before in the previous chapters, 8 course modules were prepared by the EMERALD project consortium, going through the logical chain of developing, producing and testing of bio-mechatronic systems by 3D printing, to support patients with amputated arms in the end.

2.1. EMERALD course module 1 – Computer Aided Design

The first course module of the EMERALD project on Computer Aided Design (CAD) (prepared by Poznan University of Technology) partner in the EMERALD consortium, course module that can be freely accessed on the next following link on the EMERALD project website: https://project-emerald.eu/wp-content/uploads/2023/02/EMERALD_IO1_module_1_CAD.pdf (see Figure 1) aims to approach the integration of advanced manufacturing methods, particularly 3D printing for biomedical applications. This approach allows providing information concerning the designed medical bio-mechatronic systems, including implants and prostheses, customized to individual patients. The focus of this module is to provide data on impact of 3D printing in medicine, allowing for complex, patient-specific designs that would be difficult or impossible to be realized by traditional manufacturing methods.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The Education, Scholarships, Apprenticeships and Youth Entrepreneurship
EUROPEAN NETWORK FOR 3D PRINTING OF BIOMIMETIC MECHATRONIC SYSTEMS
MODULE 1 – CAD

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Figure 1. Computer Aided Design course module of EMERALD project

Therefore, the CAD course module begins with an introduction to the advancements in additive manufacturing and its adaptation for medical needs, highlighting the importance of 3D printing in creating patient-specific, anatomically accurate medical tools, orthoses and prostheses. The module emphasizes the necessity of designing these parts using Computer-Aided Design (CAD) systems before manufacturing, detailing the use of various 3D modeling techniques such as solid, surface, wireframe, and hybrid modeling in selected CAD systems.

The course module proceeds afterwards further to a comprehensive review of popular CAD software like Autodesk Inventor, SolidWorks, and Fusion 360, discussing their features, functionalities, and applications in creating biomimetic devices. It also explores mesh processing software like MeshLab and GOM Inspect, essential for processing 3D scanned or medically imaged data to create 3D printed models. A significant part of the module is dedicated to the methodology of designing biomimetic products. This includes the process of 3D scanning or medical imaging for data acquisition, CAD designing of the biomimetic device, planning 3D printing processes, and post-processing.

The course module also covers the design of electronic circuits for mechatronic and medical purposes, including the creation of Printed Circuit Boards (PCBs), essential in mechatronic biomimetic devices. Throughout the course, there's a focus on the blend of engineering and medical knowledge required in this field.

The methodology sections guide through the steps of medical diagnosis and consultation, measurement and reverse engineering of anatomical features, and the detailed design process using CAD systems. This process encompasses converting scanned data into 3D models and preparing these models for 3D printing. The module also explores the automation of the design of medical products, highlighting the use of intelligent CAD models that can reconfigure based on entered parameters, significantly reducing the design time.

The CAD course module offers therefore an in-depth understanding and overview on the use of Computer Aided Design (CAD) systems and related software programs in designing and producing biomimetic mechatronic devices, with a particular emphasis on medical applications, bridging the gap between technical engineering skills and medical knowledge, providing a comprehensive learning experience for those interested in the field of medical 3D printing and bio-mechatronic systems for people with amputated arms.

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All information related to the CAD course module has been presented and disseminated on the Multiplier Event at University Politehnica Bucharest and International Summer School edition organized at University of Agder that have been organized in September 2022 (see Figure 2).

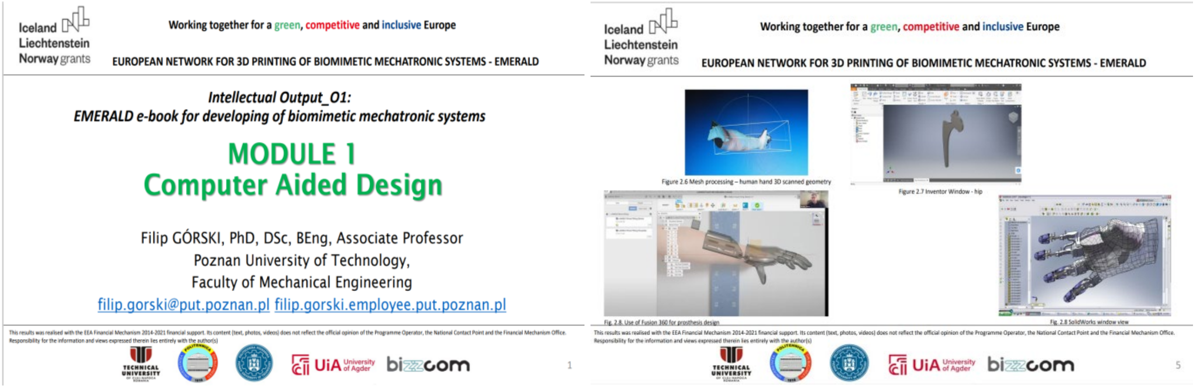
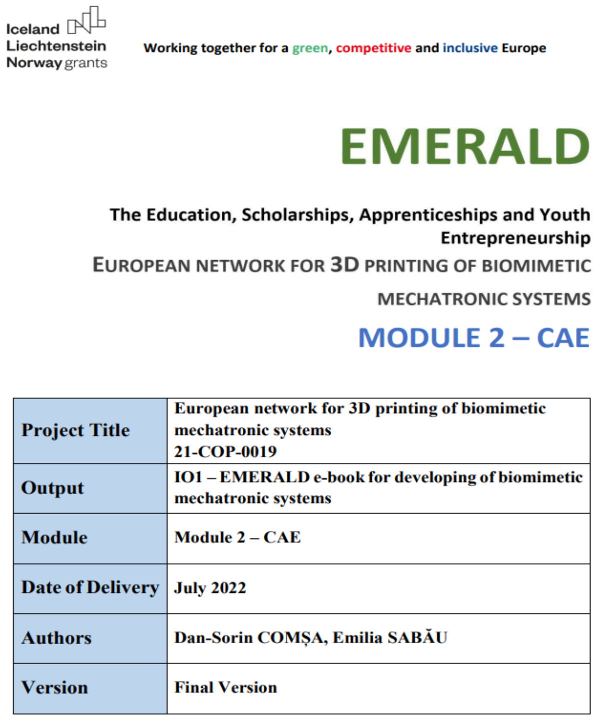


Figure 2. CAD course module disseminated on Multiplier Event and summer School organized in September 2022 by the EMERALD consortium

2.2. EMERALD course module 2 – Computer Aided Engineering

The second course module of the EMERALD project on Computer Aided Design (CAE) (prepared by Technical University of Cluj-Napoca), leading partner of the EMERALD consortium, module that can be freely accessed on the next following link on the EMERALD project website: https://project-emerald.eu/wp-content/uploads/2023/02/EMERALD_IO1_module_2_CAE.pdf (see Figure 3) aims to explore the application of CAE methods in the design and analysis of biomimetic mechatronic systems, particularly those used in medical applications. The course module focuses on providing a deep understanding of numerical methods, especially the Finite Element Method (FEM), for solving complex engineering problems. This approach is critical in validating the structural and functional integrity of medical devices, ensuring their safety and effectiveness. The module emphasizes the role of CAE in enabling precise simulations of physical phenomena, which are crucial for the development of advanced, patient-specific medical devices.

By integrating CAE methodologies with CAD designs, the course module demonstrates how engineers can efficiently predict the behavior of biomimetic devices under various conditions, a process essential for developing innovative and customized medical products, like bio-mechatronic systems for people with special needs (with amputated arms) in the end.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EUROPEAN NETWORK FOR 3D PRINTING OF BIOMIMETIC MECHATRONIC SYSTEMS

MODULE 2 – CAE

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Figure 3. Computer Aided Enginnering course module of EMERALD project

Therefore, the course module begins by exploring the numerical solution of engineering problems, primarily focusing on methods like the Finite Difference Method (FDM), Finite Element Method (FEM), and Boundary Element Method (BEM). Each method is thoroughly analyzed, highlighting its advantages, disadvantages, and suitability for various types of engineering problems. The finite difference method, for instance, is noted for its simplicity but has limitations in handling complex geometries and boundary conditions.

A significant part of the course module is dedicated to the Finite Element Method (FEM), given its widespread application in engineering. The course module goes afterwards deeper into the features of FEM, explaining how it breaks down complex problems into smaller, manageable subdomains (elements) and uses polynomial approximations to solve them.

The flexibility and adaptability of FEM in modeling various physical phenomena and complex geometries are emphasized, along with its integration with modern computer-aided design (CAD) software. Various types of finite elements are discussed, including one-dimensional, two-dimensional, and three-dimensional elements, each suited for specific types of problems. The module provides insights into selecting the appropriate element type based on the problem's complexity and the desired accuracy of the solution. It also addresses the balance between accuracy and computational effort, a key consideration in practical applications of FEM.

An integral part of the course module is a detailed case study: Finite Element Analysis (FEA) of a Wrist Hand Orthosis (WHO). This example illustrates the practical application of FEM in a medical context. The case study covers all steps involved in FEA, from preparing the model in CAD software (SolidWorks) to interpreting the results, demonstrating how to set up the model, apply material properties, define boundary conditions, and interpret stress distributions and deformations under various load conditions.

In conclusion, the course module equips learners with a comprehensive understanding of CAE tools, particularly FEM, and their applications in designing biomimetic mechatronic systems, by bridging the gap between theoretical knowledge and practical application, making it an invaluable resource for engineers and designers in the field of biomimetics and medical device development (bio-mechatronic systems for people with amputated arms) in the end.

All information related to the CAE course module has been presented and disseminated on the Multiplier Event at University Politehnica Bucharest and International Summer School edition organized at University of Agder that have been organized in September 2022 (see Figure 4).

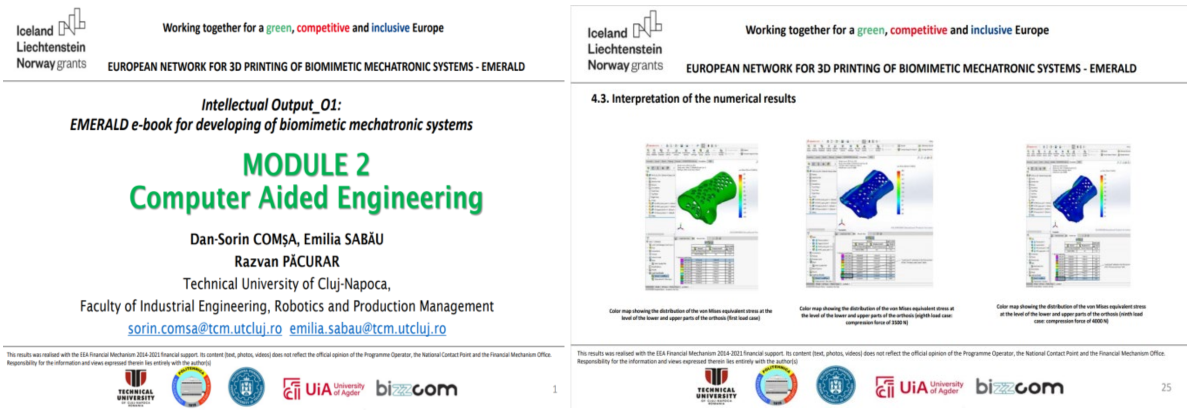
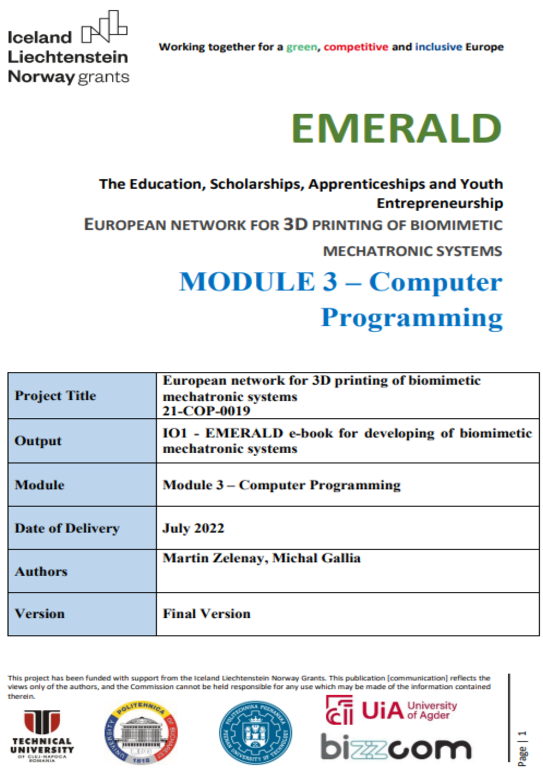


Figure 4. CAE course module disseminated on Multiplier Event and summer School organized in September 2022 by the EMERALD consortium

2.3. EMERALD course module 3 – Computer Programming

The third course module of the EMERALD project on Computer Programming (prepared by BIZZCOM company of Slovakia), industrial partner of the EMERALD consortium, can be freely accessed on the following link on the ENERALD project website: https://project-emerald.eu/wp-content/uploads/2023/02/EMERALD_IO1_module_3_ComputerProgramming.pdf (see Figure 5). This module aims to present an accessible and practical introduction to Python programming for learners with some prior programming experience. The module is structured to facilitate a smooth learning curve, starting with basic Python concepts such as strings and lists, and gradually progressing to more complex topics involving full programs that interact with text files, processes, and HTTP connections. The course material is designed to be approachable for those who have basic familiarity with programming concepts like variables and if statements, without requiring expertise in programming. This approach ensures that learners can effectively grasp Python programming and apply it in practical scenarios, particularly in the context of biomimetic mechatronic systems.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EUROPEAN NETWORK FOR 3D PRINTING OF BIOMIMETIC MECHATRONIC SYSTEMS

MODULE 3 – Computer Programming

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Figure 5. Computer programming course module of EMERALD project

In the beginning, therefore, learners are guided through the process of setting up Python on their devices, ensuring they have the necessary environment for running and editing Python programs. Python, known for its simplicity and flexibility, is a dynamic, interpreted language that does not require type declarations for variables, parameters, functions, or methods in the source code. This characteristic makes the code concise and adaptable, while also ensuring that types of all values are tracked and checked at runtime.

The course module then presents Python basics, starting with fundamental concepts and gradually building up to more complex programming exercises. These exercises include working with text files, processes, and HTTP connections. The course's structure is methodical, ensuring a solid foundation in Python basics before moving on to more advanced topics. A unique aspect of Python, which the module emphasizes, is its use of whitespace and indentation to define code blocks, instead of the braces ({ }) used in many other programming languages. This approach to coding structure might seem unusual at first, but it plays a crucial role in Python's syntax and readability.

The course module also covers in continuing essential Python features such as its runtime error checking mechanism, which defers most type, name, and other checks until the code line runs. This approach contrasts with languages like Java, where such errors are caught at compile time.

Variable naming in Python is another key topic discussed. Python's lack of explicit type declarations in the source code makes it essential to use descriptive and meaningful variable names. This practice helps maintain clarity and reduces the chances of confusion regarding the type of value a variable holds. In addition to these fundamentals, the course module explains Python's control structures, like the if statement. Python uses colons (:) and indentation to group statements within control structures, deviating from the parenthesis-based grouping seen in languages like C++ and Java. This approach contributes to Python's simplicity and readability, making it more accessible, especially for beginners.

Lastly, the course module introduces Python's list type, which is a versatile and powerful feature of the language. Lists in Python are mutable sequences, indicated by square brackets, and can be manipulated in various ways, including concatenation and slicing.

Overall, the course module provides a thorough and accessible introduction to Python programming, ensuring that learners are well-equipped with the knowledge and skills to develop Python-based applications, especially in the context of biomimetic mechatronic systems.

All information related to the Computer programming course module has been presented and disseminated on the Multiplier Event at University Politehnica Bucharest and International Summer School edition organized at University of Agder that have been organized in September 2022 (see Figure 6).

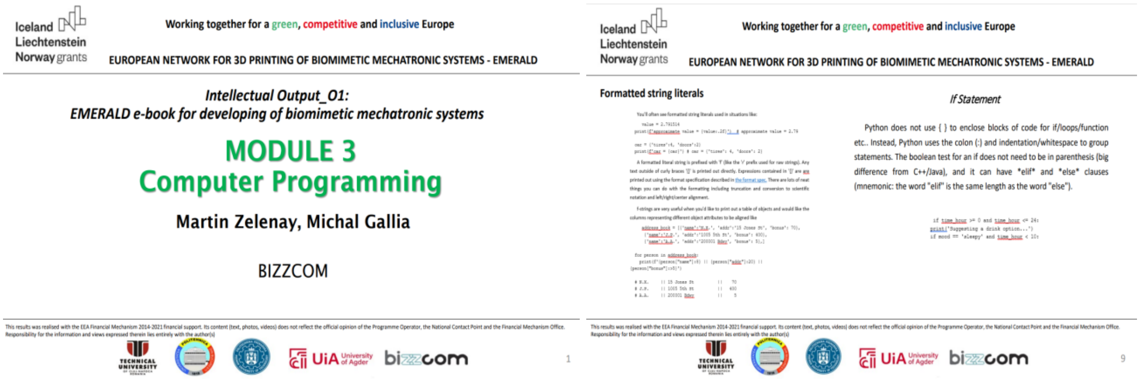
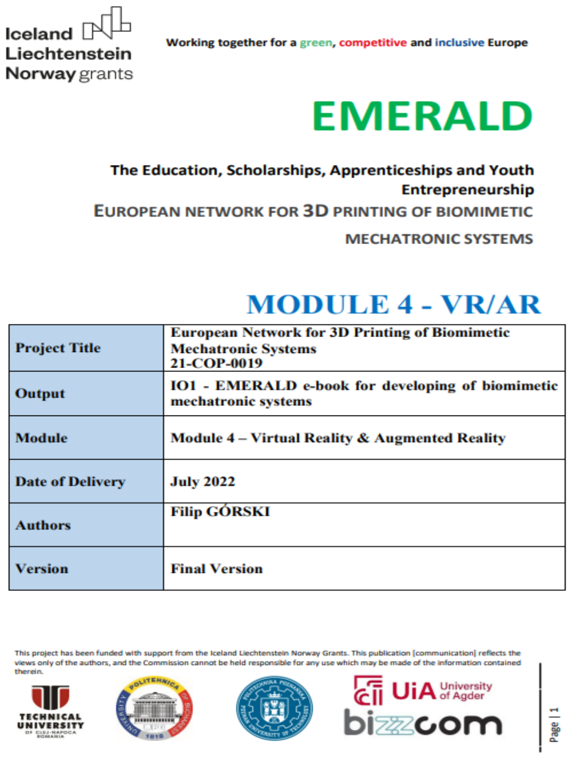


Figure 6. Computer programming course module disseminated on Multiplier Event and summer School organized in September 2022 by the EMERALD consortium

2.4. EMERALD course module 4 – Virtual Reality / Augmented Reality

The fourth course module of the EMERALD project on Virtual Reality / Augmented Reality (VR/AR), prepared by Poznan University of Technology, a partner in the EMERALD consortium, is a comprehensive course module that can be accessed at the following link: https://project-emerald.eu/wp-content/uploads/2023/02/EMERALD_IO1_module_4_VR.pdf (see Figure 7). This module aims to approach the fundamental concepts and applications of Extended Reality (XR) technologies, encompassing Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), and their transformative role in various fields, particularly in medicine, education, and engineering.

The course module starts by presenting the history and evolution of VR, highlighting its journey from a novel idea in the 1960s to a powerful tool in modern manufacturing, education, and medical training. VR's unique capability to create immersive experiences through multisensory stimulation is emphasized, along with the significant advancements in both hardware and software that have made VR more accessible and effective in recent years.



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EUROPEAN NETWORK FOR 3D PRINTING OF BIOMIMETIC MECHATRONIC SYSTEMS

MODULE 4 - VR/AR

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Figure 7. VR /AR course module of EMERALD project

Further on, in the course module, VR is defined as a high-end user interface enabling real-time simulation and interaction across multiple sensory channels. The essential characteristics of Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR) are explored, including their differences in terms of user experience and immersion. VR is presented as a fully immersive experience, while AR enhances the real world with digital elements, and MR blends both real and virtual worlds.

The technical aspects of XR (eXtended Reality) systems are also being covered, with an emphasis on the necessary hardware and software components. This includes a detailed discussion on typical consumer VR systems comprising helmets, motion controllers, and additional sensors, as well as the software tools used to develop VR applications, such as 3D engines for interactive applications and games. The applications of XR technologies in various fields are extensively discussed. The course module highlights the role of VR in industries like engineering, education, medicine, and entertainment. It points out how VR can simulate specific sections of reality to enhance learning, training, and the development of practical skills.

The course module also covers the concept of simulation in XR, distinguishing between "hard" and "soft" simulations and their relevance in creating realistic virtual environments. It outlines the essential features and functions of a VR application, including immersion, realism, and free navigation and interaction.

Furthermore, the course module goes deeper into the requirements and types of VR applications, categorizing them based on the level of knowledge they impart: general knowledge, procedural knowledge, and practical skills. This classification helps in understanding the complexity involved in developing VR systems and their varied applications.

Finally, the development process of XR applications is outlined, emphasizing the importance of the human factor in their design and implementation. The module emphasize the use of Design Thinking methodology in developing XR educational simulations and outlines the stages of XR application design, including identification, justification, and visualization.

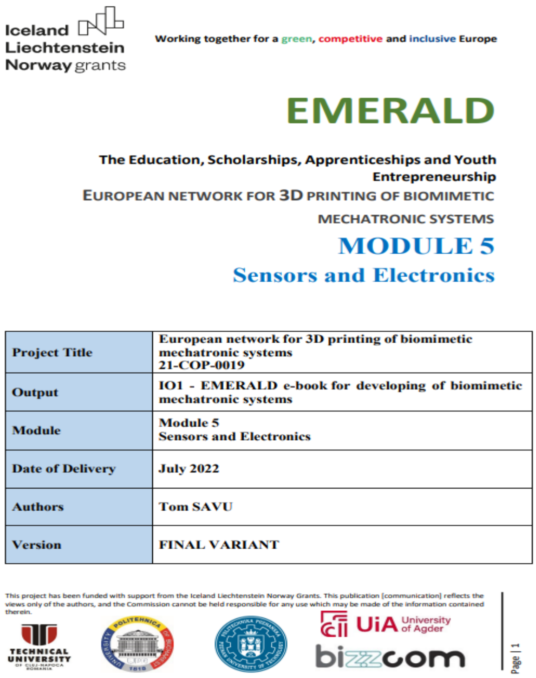
In summary, the course module provides a comprehensive overview of XR technologies, their development process, and their diverse applications, underscoring their significant impact on professional and daily life activities.

All information related to the Computer programming course module has been presented and disseminated on the Multiplier Event at University Politehnica Bucharest and International Summer School edition organized at University of Agder that have been organized in September 2022 (see Figure 8).

Figure 8. VR /AR course module disseminated on Multiplier Event and summer School organized in September 2022 by the EMERALD consortium

2.5. EMERALD course module 5 – Sensors and Electronics

The fifth course module of the EMERALD project on Sensors and Electronics (prepared by University Politehnica Bucharest), partner of the EMERALD consortium, course module that can be freely accessed on the next following link on the EMERALD project website: https://project-emerald.eu/wp-content/uploads/2023/02/EMERALD_IO1_module_5_Sensors-and-Electronics.pdf (see Figure 9) aims to explore the fundamental principles and applications of sensors and electronics in the context of biomimetic mechatronic systems.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EUROPEAN NETWORK FOR 3D PRINTING OF BIOMIMETIC MECHATRONIC SYSTEMS

MODULE 5

Sensors and Electronics

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Figure 9. Sensors and electronics course module of EMERALD project

The Sensors and electronics course module begins by introducing the concept of a measurement system, which is a collection of devices and equipment used to extract information from a process. This information typically relates to various physical quantities such as mechanical, thermal, electrical, chemical, and optical properties. It is underlined that a crucial component of any measurement system is the sensor, which is in direct contact with the observed process and undergoes changes in its parameters based on the measured physical quantity. These changes form the basis of the signal that the sensor generates.

The course module further on goes deeper on providing information related to the types of sensors and transducers, categorizing them into parametric (passive) and generative (active) sensors. Parametric sensors change some of their parameters without generating energy, while generative sensors produce energy when interacting with the observed process. These sensors can be further classified based on the variable parameter in resistive, capacitive, and inductive sensors for parametric types, and according to the physical quantity they measure for generative sensors, such as thermocouples, piezo resistive pressure sensors, and photodiodes.

An essential aspect of the course module is focused on signal conditioning, which is the process of transforming an analog signal to make it compatible with the subsequent components of the measurement system. This includes operations like input coupling, filtering, and amplification. Each of these operations plays a critical role in ensuring the integrity and usability of the signal from the sensors. The course module also covers the topic of analog-to-digital converters (ADCs), which are integral in converting analog signals into digital formats for further processing. The course explains the function, structure, and importance of ADCs in measurement systems, emphasizing the concept of resolution and its impact on the accuracy of the conversion process.

In summary, the Sensors and Electronics course module provides comprehensive knowledge about the key components and functionalities of modern measurement systems. It emphasizes the integral role of sensors, signal conditioning, and analog-to-digital conversion in the field of biomimetic mechatronic systems, equipping learners with the essential skills and understanding necessary for working in this advanced technological domain. All information related to the Sensors and Electronics course module has been presented and disseminated on the Multiplier Event at University Politehnica Bucharest and International Summer School edition organized at University of Agder that have been organized in September 2022 (see Figure 10).

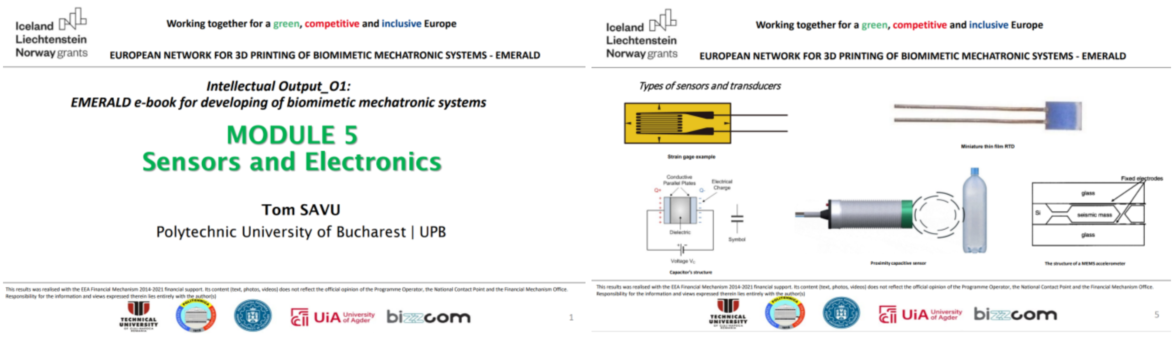
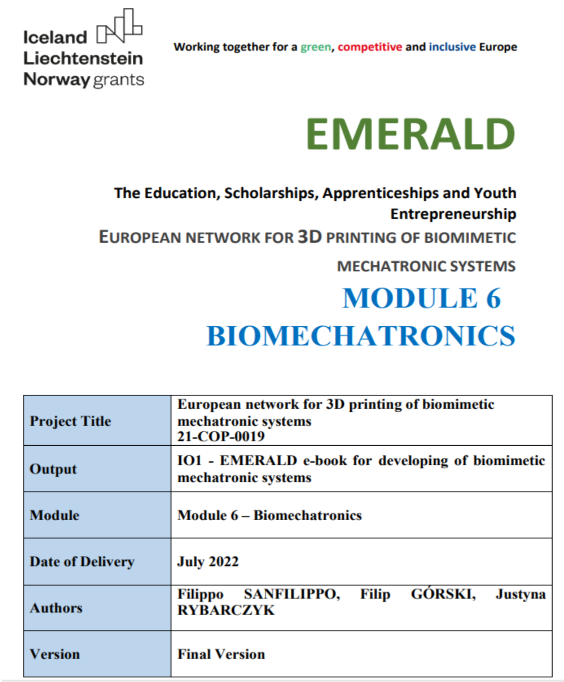


Figure 10. Sensors and Electronics course module disseminated on Multiplier Event and summer School organized in September 2022 by the EMERALD consortium

2.6. EMERALD course module 6 – Sensors and Electronics

The sixth course module of the EMERALD project on Bio-mechatronics, prepared jointly by the University of Agder and Poznan University of Technology, partners of the EMERALD consortium, that can be freely accessed at the following link on the EMERALD project website: https://project-emerald.eu/wp-content/uploads/2023/03/EMERALD_IO1_module_6_BioMechatronics_.pdf (see Figure 11) aims to provide comprehensive insights into the field of bio-mechatronics, an interdisciplinary area that combines mechanical, electronic, and biological elements to create innovative devices and systems for medical, therapeutic, and assistive purposes.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EUROPEAN NETWORK FOR 3D PRINTING OF BIOMIMETIC MECHATRONIC SYSTEMS

MODULE 6

BIOMECHATRONICS

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Figure 11. Bio-mechatronics course module of EMERALD project

Within this course module it is firstly explained that Bio-mechatronics is a subfield of biomedical engineering, being focused on the interaction between mechanics, electronics, and human biology. It seeks to create devices that restore or enhance human body functions, often lost through disease or accident, or to augment natural human abilities. This field is particularly significant for developing prosthetics, exoskeletons, and neuroprosthetic implants that can mimic natural limb movements or restore motor functions in individuals with paralysis.

The course module goes further on deeper into the basic definitions and concepts of bio-mechatronics, highlighting its role as an applied interdisciplinary science. It includes discussions on related areas such as biomechanics, bionics, and biomimetics. Bio-mechatronics integrates concepts from these fields to research and design therapeutic, assistive, and diagnostic devices. These devices are aimed at compensating for or replacing human physiological functions, which includes the development of advanced prosthetics and exoskeletons for individuals with disabilities.

Examples of bio-mechatronic devices and systems are explored in the module. These include prosthetic limbs that interact with the user's nervous system to provide intuitive control and feedback, as well as bio-mechatronic exoskeletons that assist in physical tasks and rehabilitation. The module also addresses the use of bio-mechatronic systems in medical applications, such as implantable medical devices for treating various conditions.

The potential applications of bio-mechatronics are vast and varied, ranging from bio-interfaces for diagnostics and control to robotic systems for high-speed screening and analysis. The field also encompasses the development of neural and brain stimulation devices, tele and robot-assisted surgery, and various mobility aids. Looking towards the future, bio-mechatronics could venture into areas such as brain prostheses, autonomous hospitals and nano-machines, presenting exciting prospects for healthcare and rehabilitation.

In summary, the Bio-mechatronics course module of the EMERALD project comprehensively covers the basics of this interdisciplinary field, emphasizing its immense potential in improving healthcare and rehabilitation. The course module is designed to equip learners with key concepts, technical challenges, and the vast array of applications of bio-mechatronic systems, particularly those that can be manufactured using additive manufacturing. This field, which requires a deep understanding of both biology and mechatronic engineering, is expected to grow significantly in importance in the years to come.

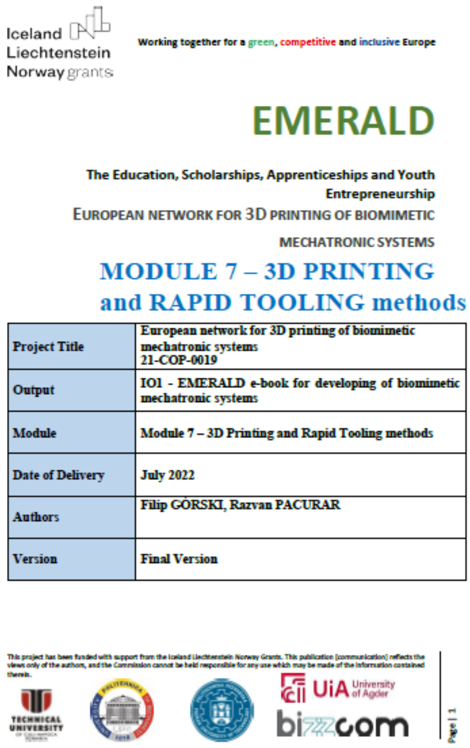
All information related to the Bio-Mechatronics course module has been presented and disseminated on the Multiplier Event at University Politehnica Bucharest and International Summer School edition organized at University of Agder that have been organized in September 2022 (see Figure 12).

Figure 12. Bio-mechatronics course module disseminated on Multiplier Event and summer School organized in September 2022 by the EMERALD consortium

2.7. EMERALD course module 7 – 3D Printing and Rapid Tooling

The seventh module of the EMERALD project on 3D Printing and Rapid Tooling, prepared jointly by Poznan University of Technology and Technical University of Cluj-Napoca, partners of the EMERALD consortium, can be freely accessed at the following link on the EMERALD project website: https://project-emerald.eu/wp-content/uploads/2023/03/EMERALD_IO1_module_7_3D-Printing.pdf (see Figure 13). This module aims to provide an in-depth understanding of additive manufacturing technology, commonly known as 3D printing, and its revolutionary impact across various domains, particularly in medicine. The course module explores the transformation in the manufacturing of medical devices and prostheses, emphasizing the creation of intricate and complex structures that were previously hard to be achieved with traditional manufacturing methods.

The 3D Printing and Rapid Tooling course module therefore begins by outlining the basic definitions and concepts related to additive manufacturing, including rapid prototyping, rapid manufacturing, rapid tooling, and the use of 3D modeling software. Further on, the 3D Printing and Rapid Tooling course module highlights the versatility and efficiency of 3D printing methods in producing end-use products and tooling rapidly and cost-effectively. The course module also discusses the significance of build volume, layer height, resolution and post-processing operations in additive manufacturing processes.



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The Education, Scholarships, Apprenticeships and Youth Entrepreneurship
EUROPEAN NETWORK FOR 3D PRINTING OF BIOMIMETIC MECHATRONIC SYSTEMS

MODULE 7 – 3D PRINTING and RAPID TOOLING methods

Project Title	European network for 3D printing of biomimetic mechatronic systems 21-COP-0019
Output	IO1 - EMERALD e-book for developing of biomimetic mechatronic systems
Module	Module 7 – 3D Printing and Rapid Tooling methods
Date of Delivery	July 2022
Authors	Filip GÓRSKI, Razvan PACURAR
Version	Final Version

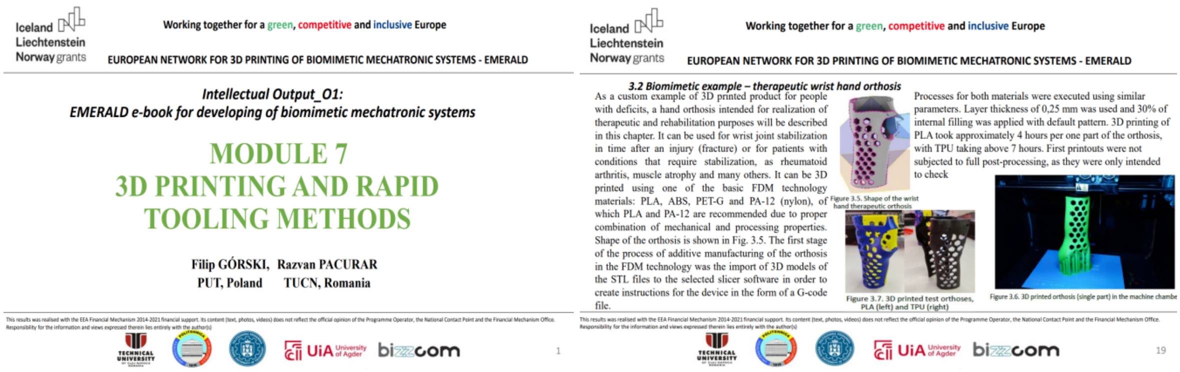
Figure 13. 3D printing and Rapid Tooling course module of EMERALD project

A detailed review of available 3D printing technologies is being provided in continuing, based on the ISO/ASTM 52900 standard, which categorizes additive manufacturing processes into extrusion, powder bed fusion, photopolymerization, material jetting, binder jetting, sheet lamination, and directed energy deposition. The 3D Printing and Rapid Tooling course module emphasizes the diversity of these technologies and their applications, ranging from low-cost hobby-like machines to industrial-grade professional devices.

The 3D Printing and Rapid Tooling module also goes deeper into the preparing of 3D printing processes, discussing various data formats like STL, OBJ, and AMF, and their specific uses and advantages in additive manufacturing. Also in the course module is underscored the importance of selecting the right data format to accurately represent the object's design, shape, size, and material properties. Additionally, the 3D Printing and Rapid Tooling course module highlights the role of slicer software in planning and executing of the 3D printing processes, detailing how it generates instructions for 3D printers and allows adjustments of various parameters affecting the quality and accuracy of the printed object in the end.

Furthermore, the 3D Printing and Rapid Tooling course module showcases examples of 3D printed biomimetic devices, illustrating the vast potential of 3D printing in medical applications. These examples include artificial joints, heart valves, skin tissue, bones, cartilage, blood vessels, prosthetic feet, and orthoses, all of which demonstrate the capability of 3D printing technologies to produce customized and functional medical devices that closely mimic natural anatomy and offer improved patient outcomes.

In summary, the 3D Printing and Rapid Tooling course module of the EMERALD project comprehensively covers the foundational aspects and advanced applications of 3D printing technologies, emphasizing their transformative role in various fields, particularly in creating personalized, biomimetic medical devices and tools that significantly enhance patient care and medical procedures in the end. All information related to the 3D Printing and Rapid Tooling course module has been presented and disseminated on the Multiplier Event at University Politehnica Bucharest and International Summer School edition organized at University of Agder that have been organized in September 2022 (see Figure 14).



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EUROPEAN NETWORK FOR 3D PRINTING OF BIOMIMETIC MECHATRONIC SYSTEMS - EMERALD

Intellectual Output_O1:
EMERALD e-book for developing of biomimetic mechatronic systems

MODULE 7
3D PRINTING AND RAPID TOOLING METHODS

Filip GÓRSKI, PUT, Poland — Razvan PACURAR, TUCN, Romania

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3.2 Biomimetic example – therapeutic wrist hand orthosis

As a custom example of 3D printed product for people with deficits, a hand orthosis intended for realization of therapeutic and rehabilitation purposes will be described in this chapter. It can be used for wrist joint stabilization in time after an injury (fracture) or for patients with conditions that require stabilization, as rheumatoid arthritis, muscle atrophy and many others. It can be 3D printed using one of the basic FDM technology materials: PLA, ABS, PET-G and PA-12 (nylon), of which PLA and PA-12 are recommended due to proper combination of mechanical and processing properties. Shape of the orthosis is shown in Fig. 3.5. The first stage of the process of additive manufacturing of the orthosis in the FDM technology was the import of 3D models of the STL files to the selected slicer software in order to create instructions for the device in the form of a G-code file.

Figure 3.5. Shape of the wrist hand therapeutic orthosis

Processes for both materials were executed using similar parameters. Layer thickness of 0,25 mm was used and 30% of internal filling was applied with default pattern. 3D printing of PLA took approximately 4 hours per one part of the orthosis, with TPU taking above 7 hours. First printouts were not subjected to full post-processing, as they were only intended to check

Figure 3.7. 3D printed test orthoses, PLA (left) and TPU (right)

Figure 3.6. 3D printed orthosis (single part) in the machine chambe

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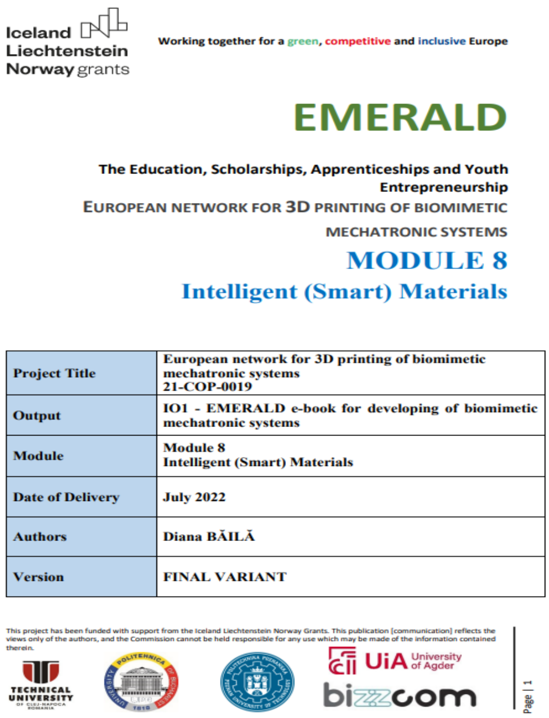
Figure 14. 3D printing and Rapid Tooling course module disseminated on Multiplier Event and summer School organized in September 2022 by the EMERALD consortium

2.8. EMERALD course module 8 – Intelligent (smart) materials

The eighth course module of the EMERALD project on Intelligent (Smart) Materials, prepared by the University Politehnica Bucharest, partner of the EMERALD consortium, can be accessed freely on the next following link on the EMERALD project website: https://project-emerald.eu/wp-content/uploads/2023/02/EMERALD_IO1_module_8_Intelligent-Smart-Materials.pdf (see Figure 15).



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EUROPEAN NETWORK FOR 3D PRINTING OF BIOMIMETIC MECHATRONIC SYSTEMS

MODULE 8

Intelligent (Smart) Materials

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Figure 15. Intelligent (smart) materials course module of EMERALD project

The Intelligent (smart) materials course module aims to provide a detailed understanding of intelligent or smart materials and their applications in various technological fields, including bio-mechatronics, medical devices, and other advanced engineering sectors.

The Intelligent (smart) materials course begins by defining intelligent materials as those that can react to changes in their environment in a controlled manner. These materials are distinguished by their ability to respond to external stimuli such as temperature, pressure, electric and magnetic fields, pH, or chemical compounds. The course module goes deeper into the different types of smart materials, including piezoelectric, magnetostrictive, shape memory alloys, and electrostrictive materials. Each type of category of materials is explored in detail, highlighting its unique properties, mechanisms of action, and potential applications.

A significant focus of the Intelligent (smart) materials course module is on the medical applications of intelligent materials. These materials are particularly valuable in the development of innovative medical devices and systems, such as drug delivery systems, diagnostic tools, and prosthetics. The course module discusses further on how smart materials contribute to the advancement of medical technology by enabling more precise, efficient, and adaptive treatments.

The course module also examines the integrating of intelligent materials in bio-mechatronic systems, where they enhance the functionality and efficiency of devices that interact with biological systems. Examples include prosthetics and orthotics that adapt to the user's movements, artificial muscles that mimic natural muscle function and sensors that monitor physiological parameters.

In summary, the Intelligent (Smart) Materials course module of the EMERALD project provides a comprehensive overview of smart materials, their properties, mechanisms, and applications, underscoring the significant role that these materials play in advancing technology, particularly in the medical and bio-mechatronic fields, where they offer new possibilities for innovation and improved quality of life of patients.

All information related to the Intelligent (Smart) Materials course module has been presented and disseminated on the Multiplier Event at University Politehnica Bucharest and International Summer School edition organized at University of Agder that have been organized in September 2022 (see Figure 16).

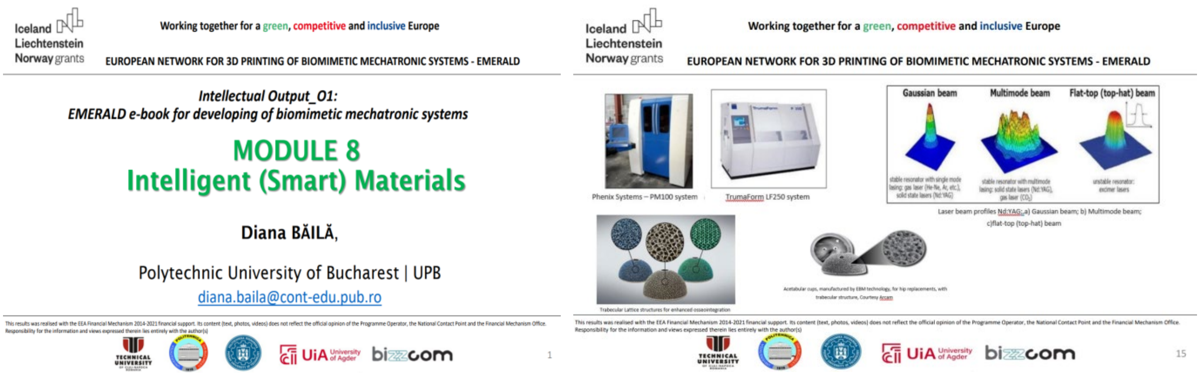

Figure 16. Intelligent (Smart) Materials course module disseminated on Multiplier Event and summer School organized in September 2022 by the EMERALD consortium

3. Conclusions

As it was mentioned in the introductory chapter, the curriculum proposed by the EMERALD consortium comprises eight modules (Computer-Aided Design (CAD), Computer-Aided Engineering (CAE), Computer Programming, Virtual Reality/Augmented Reality (VR/AR), Sensors and Electronics, Intelligent (Smart) Materials, 3D Printing and Rapid Tooling, and Bio-mechatronics) that were realized under the coordination of the Technical University of Cluj-Napoca (TUCN), leading partner of the EMERALD project consortium These modules were developed by the all partners of the EMERALD project, providing not just theoretical knowledge, but also highly practical examples based on the EMERALD consortium extensive experience and expertise in developing, producing, and testing of bio-mechatronic systems. The eight course modules were created therefore with a focus on particularizing bio-mechatronic systems for specific case studies, particularly for people with special needs, such as those with amputated arms. The modules were shared with participants at various events (Multiplier event / International Summer School event) in 2022. Furthermore, the results achieved within Intellectual Output 1 regarding course modules have been integrated within the e-learning virtual laboratory platform that has been developed by the consortium in the frame of Intellectual output 3. The curriculum is aimed at offering comprehensive knowledge to equip learners with the skills needed for the development and application of biomimetic mechatronic systems / bio-mechatronic systems (prostheses, orthoses, robotic hands) to support people with special needs (with amputated arms). In conclusions, the EMERALD project curriculum on biomimetic mechatronic systems is a well-rounded educational resource, combining theoretical knowledge with practical insights. The course modules, prepared by the EMERALD consortium partners, are available for open access freely on the EMERALD project website at https://project-emerald.eu/?page_id=23 providing valuable learning and educational material and tools for a wide range of learners and practitioners that are highly interested on the field of conceiving, realizing and testing of bio-mechatronic systems to support people with special needs (with amputated arms) in the end.