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Training for Sustainable and Healthy Building for 2050: New Methodologies for an Integrated and Transnational Education Approach Targeting Skills Development for the Transition Toward ZEB and PEB Buildings

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Abstract: The development of existing technologies and the emergence of new technologies aiming at the total decarbonization of the buildings sector by 2050 requires and encourages upskilling and reskilling of existing professionals as well as the development of new subjects from higher education courses to be able to respond to the demands of these challenges. In responding to those challenges, the main objective of the research is to design, implement, and evaluate a novel, integrated, and transnational educational approach aimed at equipping professionals and students in the construction sector with the necessary skills to achieve sustainable and energy-efficient buildings. This study aligns with the European Union's 2050 decarbonization goals by developing innovative methodologies that address the multidisciplinary challenges of sustainable building design, operation, and renovation. The proposed educational approach was developed in the framework of an Erasmus+ project entitled "Training for Sustainable and Healthy Building for 2050 (BUILD2050)". Six higher education institutions from five European countries joined forces to create transversal skills in the building sector knowledge for emerging challenges through an integrated training composed of eight training courses for students and professionals of the construction area. In this work, the pedagogical approach used to develop the course contents, curricular development issues, technology, and infrastructure, as well as student support, the results obtained from the evaluation carried out after the pilot training of the eight training courses, and best practices and lessons learned, are presented and discussed. The courses' learning objectives, the learning material, and the assessment activities were well-accomplished. However, based on the feedback of students and teachers, some improvements for future editions of the courses are required.

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1. Introduction

Climate change presents significant challenges for the built environment [1]. Buildings are one of the largest sources of energy consumption in Europe [2,3]. The challenge for the European Union for 2050 is to decarbonize the economy, where buildings have an important role in this goal [2,3]. To achieve this objective, it is necessary to develop technologies in an integrated way and, in a holistic approach, properly adapted to climatic, cultural, and natural resource conditions through circular economy methodologies. The design and construction of zero-energy buildings (ZEB) and positive-energy buildings (PEB) include not only energy-efficient interventions and implementation of renewable energy sources (RES) targeting the minimization of energy needs, but also an effective grid integration to manage the balance between consumption and production, which requires a multidisciplinary approach.

In the future, buildings should be designed to be resilient, mitigating environmental impacts while resisting the implications of climate change and other natural disasters. These new buildings need to maintain a healthy and comfortable environment for the occupants. Simultaneously, these buildings must be economically sustainable concerning operation and maintenance. Those are renewable energy sources, water consumption reduction, sustainable and long-lasting materials, and methods of construction. Green roofs and rainwater harvesting facilities are part of this vision. The countries of Southern Europe are more sensitive in this respect, especially because increased temperatures and frequency of droughts enhance water shortages [4]. Water management, often less considered in building design, shall be oriented toward water efficiency, recycling, and rainwater harvesting according to the principles of the circular economy [5]. Adopting the principles of circular water management within buildings can be expected to reduce their ecological footprint, bringing increased sustainability.

For the transition toward ZEB and PEB, skills development is essential, with training systems that quickly react to changing job requirements [6]. The main challenge to decarbonize buildings is basically the refurbishment of existing buildings and the integration of renewable energy systems that fulfill building energy needs. Energy storage, smart grids, and building automation are also key elements for this challenge. There is a training gap in sustainable, healthy construction and the promotion of well-being, complemented by its circularity, efficiency in the use of resources, and restitution of the resources used. The development of existing technologies and the emergence of new technologies aiming at the total decarbonization of the buildings sector by 2050 requires and encourages upskilling and reskilling of existing professionals and new subjects from higher education courses to be able to respond to the demands of these challenges. Thus, education should use new ways to cover the needs of different professionals with different educational backgrounds [7–10].

In line with the above, in BUILD2050 [11], six higher education institutions from five European countries joined forces to create transversal skills in the building sector knowledge for emerging challenges through an integrated training composed of eight courses for students and professionals of the construction area. The universities and partners are IPS (Instituto Politécnico de Setúbal from Portugal), NKUA (National and Kapodistrian University of Athens from Greece), UNIBO (Università di Bologna), Alma Mater Studiorum (UNIBO) from Italy, SGGW (Szkola Glowna Gospodarstwa Wiejskiego/Warsaw University of Life Sciences from Poland), POLIMI (Politecnico di Milano from Italy), and RUB (RUHR-Universitaet Bochum/RURH University Bochum from Germany).

Project BUILD2050 was divided into three phases. In the first phase, from February 2022 to February 2023, the pedagogical framework was designed to set the learning objectives, contents, teaching, and learning activities and assessments to be implemented by the course leaders of the eight training courses and their team teachers. Also, associated partners were added to the BUILD2050 network, and dissemination activities were carried out in this phase. In the second phase, from March 2023 to March 2024, the 8 training courses were sequentially taught, involving around 50 different teachers from the 6 higher education institutions and 85 different trainees of the 5 European countries. At the end of each training course, two anonymous surveys were carried out, one by the trainees and another by the teachers, to collect their feedback. In the third phase, from April 2024 to January 2025, the analysis of the surveys' responses; the setting up of the BUILD2050 platform, an open access repository of all the information generated in the project and a point of connection between all participants, organizations, and associated partners; and the production of the BUILD2050 eBook were held to guarantee the sustainability of the project.

The contents of the eight training courses were carefully selected to cover all the issues and knowledge that the professionals should acquire, from innovative construction materials to modern technologies for heating, cooling, and ventilation, as well as RES implementation in buildings, business models in construction, and circular water management in buildings to digitation of buildings and smart grid integration. The educational methodology applied is innovative, as it is a set of short courses, which are complementary but autonomous and in which knowledge is made in a circular and complementary way of basic knowledge, with a practical application considering the multidisciplinary nature of the subject.

In this work, the pedagogical approach used to develop the course contents, curricular development issues, results obtained from the evaluation carried out after the pilot training of the eight training courses (Figure 1), and proposals for future editions are presented and discussed [11]. In Course 1, the determination of legal and regulatory requirements relating to buildings and the analysis of them today and in 2050 are presented, familiarizing the participants with the standards for testing laboratories and accrediting and certifying materials for zero-emission buildings. Also, the upcoming construction challenges are addressed. In Course 2, a presentation is attempted on the required steps and technologies to achieve ZEB and PEB. In Course 3, the requirements for the implementation of circular water management in buildings are discussed together with the analysis of what was done in buildings a few centuries ago in relation to water use. Course 4 focuses on new approaches for materials used in construction and their applications. Course 5 focuses mainly on building management systems and data collection processes. Course 6 focuses on practices and techniques used in construction both at research and practical levels. Course 7 addresses the Life Cycle Analysis (LCA) method applied to buildings, considering biogenic carbon for construction materials, etc. Finally, Course 8 addresses the future challenges in construction, emphasizing the importance of developing innovative business models that align with circular economy principles.

Initially, the learning objectives for all courses were defined through discussions between the academic course leaders and both academic and non-academic stakeholders to align with student expectations and market demands. The final course contents were determined after extensive deliberations within the course working teams.

Each partner was responsible for publicizing the pilot training using the dissemination package of open-call documents to join BUIILD2050 courses. They could use their own channels (social media, such as Facebook, LinkedIn, Twitter, and Instagram-official pages of schools; master's degrees; academic institutions' websites; newsletters/mailing lists;

Italian professional orders of engineers and architects; etc.). The students' recruitment was based on CV and profile evaluation, with the support of a presentation letter and some open questions to assess:

- the interest in participating in the pilot training: question#1: The main objective of the project is the improvement of the construction and operation of buildings in Europe by developing integrated and transnational training. What does it mean for you to participate in pilot training?
- the interest in international dimension/activities: question#2: The BUILD2050 project is open to the European level. Do you feel confident working with an international/interdisciplinary group? Do you ever join initiatives abroad (i.e., summer schools, international congress or events, etc.)?
- the ability to go out of your comfort zone and face challenges: question#3: Seventy participants from six different countries will be selected for the pilot training. How challenging is this for you?
- the ability to work in a team and their role expectations: question#4: Which role in the working group do you think is more suitable for you?
- the learning ambitions: question#5: What do you expect from these courses? What are your ambitions?

Students presented their application by filling in the Google Form with the following sections: (i) Personal information and qualification/job position; (ii) English level (self-declaration); (iii) Expertise in computer skills (software); (iv) Open questions; (v) Rating the interest in each course with a 1 to 5 scale; and (vi) upload of CV and presentation letter (max 300 words). Then, all the applications were collected in an Excel spreadsheet.

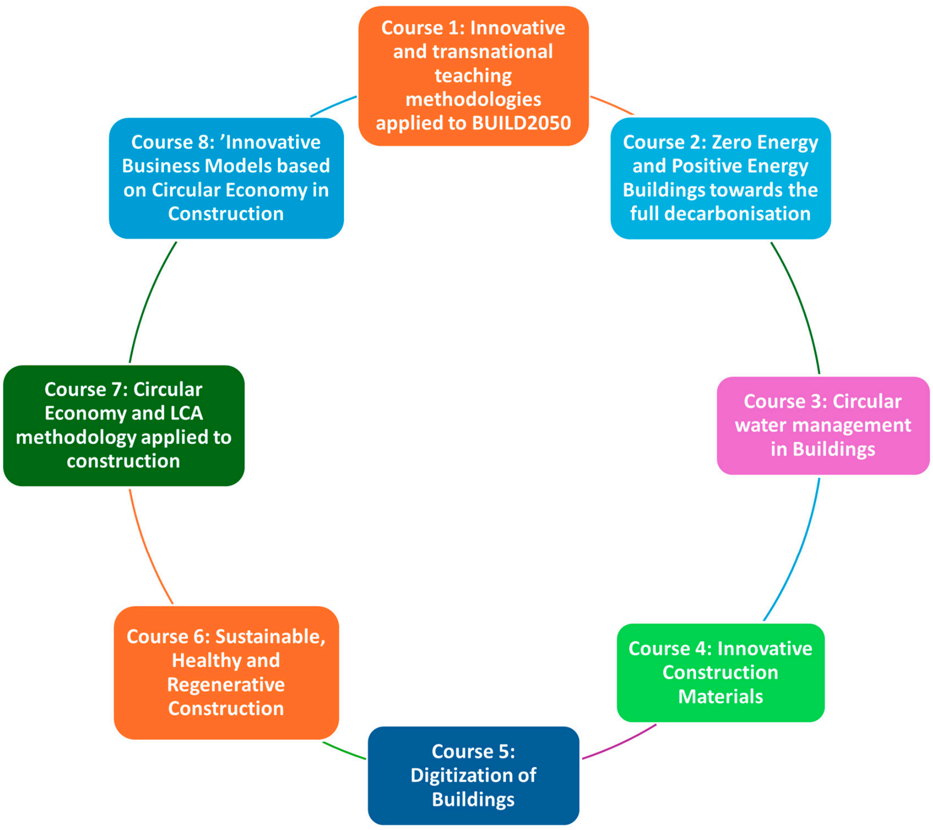

Figure 1. Training courses of BUILD2050.

A selection committee with at least two members from each partner was responsible for selecting the candidates from their country by evaluating their eligibility and interest in joining the pilot training, providing short comments (max 20 words), and delivering the final decision. All the candidates were eligible for the courses and notified of the positive decision.

Data collection methods included pre- and post-course surveys to gather participants' feedback, structured interviews with course leaders and instructors, and performance assessments such as quizzes, assignments, and group projects. Additionally, engagement metrics such as attendance rates and participation in both synchronous and asynchronous activities were tracked. The analysis combined quantitative methods, such as statistical evaluation of quiz scores and completion rates, with qualitative approaches, such as thematic analysis of survey and interview responses, to assess the courses' effectiveness and the achievement of learning objectives. Finally, the best practices and key lessons learned were identified to propose targeted improvements for future editions of the courses.

2. Materials and Methods

2.1. Pedagogical Approach

The eight training courses, due to the transnational approach of BUILD2050, introduce pedagogical challenges. First, they are supported by course leaders from different educational institutions and countries, with their different cultures and teaching approaches. For that reason, the training method to be applied should be flexible and adaptable to the characteristics of transnational teachers. Furthermore, since students are also from different academic institutions, countries, and areas of knowledge, a mix of learning techniques and innovative training methods should be considered to achieve the learning objectives of the training courses.

Designing innovative training courses starting from scratch requires careful planning and a suitable pedagogical approach to be implemented [12,13]. From the reflection on the goals and challenges of the pedagogical component of pilot training BUILD2050, it was proposed to prepare and integrate the course leaders into the student-centered approach [14] to support them in the development of the design of each training course and, consequently, to prepare the team of teachers and researchers teaching in these courses. To this end, based on the background experience of the five-step pedagogical design for engineering courses [15], already designed and tested in typical technical and engineering course units, a specific set of five pedagogical learning activities for the course leaders was developed to be applied in the context of project BUILD2050 features. The five-step pedagogical framework for BUILD2050 (Figure 2), based on tasks to be performed in a specific time frame in each step and supported by video and audio slides, was carried out over seven months, from July 2022 to January 2023, by the eight course leaders to integrate the pedagogical elements of a student-centered approach into their training courses [16].

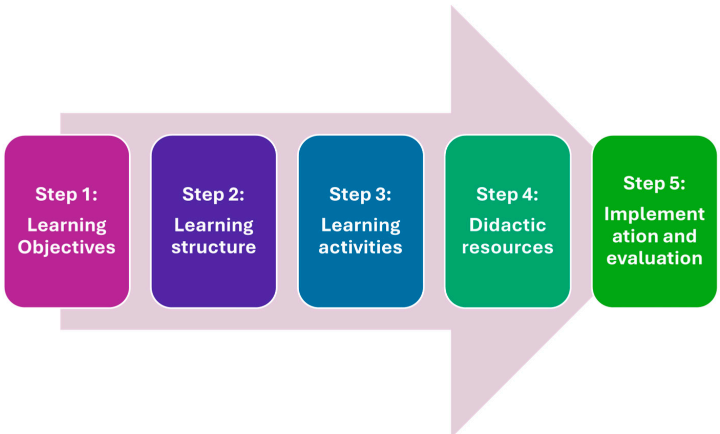

Figure 2. Five-step pedagogical framework for BUILD2050.

The application/operationalization of this pedagogical approach was conducted for all training courses, which were sequentially taught during the pilot training held from March 2023 to March 2024. At the end of each training course, two short anonymous surveys were carried out, one by students attending the pilot training and another by teachers who taught in each training course, to report their feedback about the application of the pedagogical approach.

2.2. Curricular Development

2.2.1. Methodology

The working teams for each course were initially defined based on the specialties that each institution could guarantee. At least one member from each institution was involved in each course. For each course, a leader who organized and distributed the work was assigned. IPS was the leader of Courses 1 and 3. NKUA was the leader of Courses 2 and 8. UNIBO was the leader of Courses 4 and 6. SGGW was the leader of Course 7; POLIMI was the leader of Course 5, while RUB supported most of the courses. Before the start of the courses, each course leader was responsible for collecting the content and defining the program. That phase lasted about a year and consisted of the identification of learning objectives and main topics, teachers as experts in the field for each course, and final coordination with all course leaders to have a well-structured pilot training without unnecessary overlapping and repetitions. The search for innovation and delivering original concepts were considered the main drivers to disseminate novelty, foster the acquisition of critical thinking, and develop relevant courses aligned with the Project BUILD2050 goal. Curricula were typically designed with a few key strategies to meet the needs of transnational students. These approaches aim to address both educational and cultural diversity while ensuring practical application across different countries and contexts.

For the development of course structure and content, work started with the definition of appropriate learning objectives. Then, the first version of the course content was defined. Lastly, after some iteration, the final course content was decided. Learning objectives were specific; they can be measured and time-specific to monitor their achievement. The learning objectives were defined utilizing Bloom's Taxonomy and by discussion between the academic course leader and the academic and non-academic to align with both student expectations and market demands. This process ensured the courses met academic standards while preparing students for real-world challenges, aligning their education with their career goals and the evolving needs of the building sector targeting ZEB and PEB. This alignment made the courses both relevant and practical for preparing students for future challenges in the transnational construction and infrastructure sectors.

All training courses were taught sequentially, with a logical content sequence and 25 attendance hours each (5 h per week on average). The students attending the courses are graduates or professionals of architecture, physics, environmental engineering, civil engineering, mechanical engineering, power engineering, and other engineering fields from the countries of the academic institutions pointed out.

The courses use a blended approach with synchronous sessions on platforms like Teams, featuring interactive lectures, case studies, group discussions, and real-time tools like polls and breakout rooms to engage students. Asynchronous activities on Moodle include recorded lectures, expert interviews, assignments, and discussion forums. Active learning methods such as project-based tasks, role-playing, and flipped classrooms enable students to apply practical concepts, such as Life Cycle Analysis (LCA) in Course 7 or sustainable design proposals in Course 6. Collaborative assessments and immediate feedback ensure an inclusive and engaging learning experience. The assessment for evaluating students ranges from multiple-choice quizzes to group assignments or coding challenges.

The instructional design approach adopted in creating the courses was centered around active and experiential learning, incorporating a blend of theoretical knowledge and practical application. It was selected to meet the needs of transnational learners, support diverse learning outcomes, and integrate the latest trends in education and construction technology. The design emphasized learner engagement through synchronous lectures, case studies, exercises based on real examples, and article analysis, ensuring that students could apply the concepts they learned in a practical context. All the instructional materials were made available as PDF presentations, recorded slideshow presentations, recorded interviews, and videos with subtitles to promote accessibility and inclusivity in the course. Also, a reference person for each course was at the students' disposal for support in any technical issues related to synchronous, asynchronous, and assessment activities.

Flexibility in course delivery, such as the use of online platforms and modular structures, allowed students to engage with the material at their own pace and from various locations, for ensuring accessibility and inclusivity has been essential due to the diverse, transnational student base and the wide range of technological competencies. To promote accessibility and inclusivity, several strategies were implemented, addressing both the technical accessibility of course materials and the cultural inclusivity necessary for a global learning environment.

2.2.2. Course Learning Objectives and Contents

The courses share a set of overarching objectives aimed at equipping students and professionals with market-oriented skills, fostering critical thinking, and promoting a deeper understanding of sustainable construction practices. These objectives include aligning course content with industry demands, integrating historical and contemporary perspectives, and applying interdisciplinary approaches to address complex challenges in sustainable building design and operation. While each course is tailored to specific topics, such as innovative materials, circular economy, or building digitization, they collectively emphasize practical application, active learning, and development of transversal skills to meet the evolving needs of the construction sector. This unified foundation ensures consistency while allowing each course to focus on its unique content and implementation.

In the following, specific information for each course, including learning objectives and content, is provided.

Course 1: The learning objectives are (Figure 3) (1) definition of buildings' legal and regulatory requirements and (2) analysis of the situation for buildings today and in 2050. The process of defining and aligning learning objectives with both student expectations and market demands in Course 1 would have involved a strategic combination of educational theory, industry analysis, and stakeholder engagement.

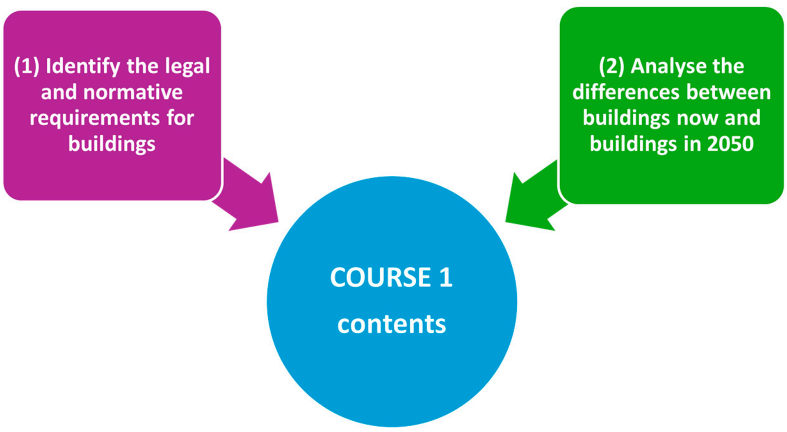

Figure 3. Course 1 learning objectives.

The goal would be to ensure that students are gaining skills that are not only academically robust but also highly relevant to the evolving needs of the construction and infrastructure sectors in a globalized, transnational context. The instructional design of the course likely adopted a combination of competency-based learning, project-based learning, and technology-enhanced learning approaches. These methodologies ensured that the course was practical, industry-aligned, and transnationally applicable, preparing students for the demands of the modern construction industry [17]. Backward design and scaffolded learning helped structure the learning experience around specific, measurable outcomes, ensuring that students achieved both theoretical understanding and practical skills relevant to their professional goals. Instructional materials were structured with the goal of creating an engaging and interactive learning environment that allowed students to apply concepts in real-world contexts, collaborate with peers, and build the skills necessary for transnational project management and innovative construction practices. They were designed to promote active learning and student engagement through a combination of interactive technologies, real-world projects, collaborative activities, and hands-on simulations. By incorporating strategies such as project-based learning, case studies, and digital tools, the course ensured that students were not passive recipients of information but active participants in their learning process. This approach was crucial for preparing students to succeed in the rapidly evolving, tech-driven, and transnational construction industry.

The strategies implemented in Course 1 to promote accessibility and inclusiveness were diverse and targeted both technical and cultural aspects of the learning experience. By incorporating support, flexible learning formats, accessible digital platforms, and culturally responsive teaching, the course ensured that all students, regardless of their abilities, geographical location, or cultural background, could engage with the content fully. These efforts were crucial for creating a globally inclusive learning environment that addressed the unique challenges of transnational education in the construction sector.

Course 2: This core course covered a wide range of topics according to the learning objectives that were defined (Figure 4): (1) Study of energy use in buildings and calculation for systems used in ZEB/PEB, (2) Introduction to technologies employed in ZEB/PEB, and (3) Evaluation and selection of energy-reduction measures.

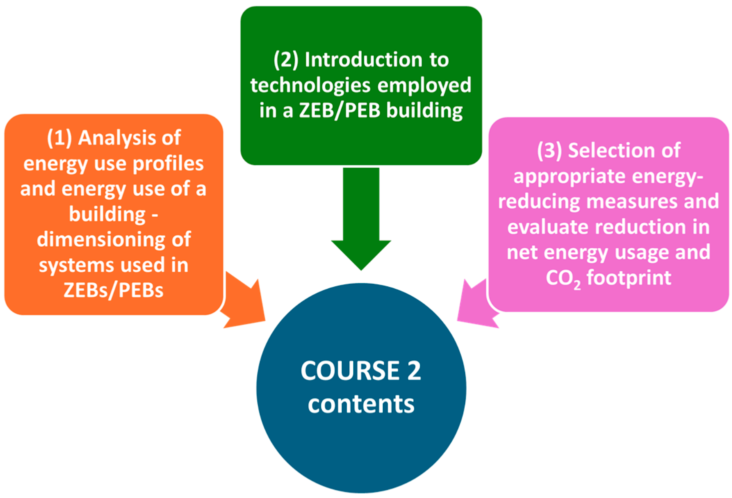

Figure 4. Course 2 learning objectives.

To achieve the learning objectives, Course 2 contents are based on a modular approach for the synchronous and asynchronous sessions. The course comprises five modules covering mainly the technical and design dimensions necessary to practically engage the participants on the topic. Module 1 focuses on the building envelope and energy performance definition of ZEB and PEB from a building scale to a district scale. Building energy-efficiency indicators (energy use and primary energy); values of new and existing buildings; and factors affecting performance (envelope, ventilation, and HVAC systems) are also discussed. Module 2 focuses on indoor environmental quality, thermal comfort, and optical comfort in buildings and related standards and regulations. Technologies to improve indoor air quality, ventilation systems, techniques and technologies to improve the building microclimate, and current trends in lighting are also discussed. Module 3 focuses on energy consumption and use in buildings; current trends in heating, cooling, and DHW systems; passive building interventions, etc. Module 4 is dedicated to RES applications for buildings. RES in the built environment and energy storage to meet ZEB/PEB goals [18], introduction to photovoltaic and battery energy storage system applications in buildings, geothermal heat pumps and thermal energy storage [18], and biomass conversion utilization of agglomerates are discussed. Module 5 focuses on energy management and automation in buildings. BMS technologies and IoT and energy management systems in buildings with solar thermal power and PCM thermal energy storage [18] are discussed. Integration of electric vehicles and charging infrastructure within the built environment and grids are part of the content. Issues related to connection to the grid and other networks, energy communities, positive energy districts, user inclusion, and social issues are also included.

The instructional materials were prepared for synchronous and asynchronous activities. Synchronous activities consisted of face-to-face remote lectures, where teachers made their presentations available for online discussion with students. For asynchronous activities, interviews and recorded presentations were uploaded to the Moodle platform, and students were able to study them. Guest speakers from the industry were invited to give interviews on various topics. Representative from ASHRAE Greek chapter talked about ASHRAE standards for ventilation and indoor air quality; representatives from companies talked about massive façades, decentralized ventilation systems, recent trends, standards, and practices for indoor lighting systems to achieve optical comfort results. Also, representatives from Solar Heat Europe talked about current trends and future challenges for solar thermal collectors and PVs for buildings, while invited lectures about IoT systems for buildings in practice and building management systems were included. Finally, results from related European research projects were presented and analyzed.

Course 3: The course was created for international professional students working or studying in architecture, engineering, urban planning, environmental sciences, and other related fields. This variety of experiences is important since water management in buildings is not a one-dimensional issue. Participants typically have varying levels of experience with the topic; some are beginners, while others are professionals wishing to expand their knowledge on circular water management. Architects and designers are often more interested in learning how to incorporate sustainable water use into buildings, whereas engineers are more concerned with implementing these systems. Urban planners aim to study how circular water use may be implemented in the larger context of urban planning, while environmentalists are more concerned with the environmental impact of water use in buildings. Since water management in buildings requires a multidisciplinary approach, the course was designed to include different experience levels, from beginners to professionals. The content was created to be globally relevant, focusing on both historical and contemporary water management practices, and include real-world case studies to ensure practical use. The course included practical learning activities, such as case studies, group discussions, and projects, which encouraged participants to apply theoretical knowledge in real-world scenarios. This hands-on approach facilitated peer learning, enabling students from different countries and professions to share insights and collaborate on projects, further enriching the learning experience.

The learning objectives were defined by aligning both student expectations and the current broader market demands in the field of sustainable building practices. The learning objectives focus on addressing critical issues like circular water management, comparing historical and modern practices, and understanding the implementation of sustainable solutions in both new and existing buildings. Three learning objectives were defined (Figure 5): (1) define the basics of circular water management; (2) compare water management in old and new buildings; and (3) explain requirements to implement circular water management in old and new buildings. The course was designed using a learner-centered and interdisciplinary approach that emphasized active engagement and practical application. A modular framework was used, with each session gradually building on knowledge and skills, ensuring that participants could understand complicated issues like circular water management in a step-by-step manner. The design also included a mix of customized learning materials, hands-on activities, and expert guest speakers to accommodate the participants' different professional backgrounds. This strategy ensured that the curriculum was both flexible and comprehensive, meeting the diverse learning needs and professional goals of the students.

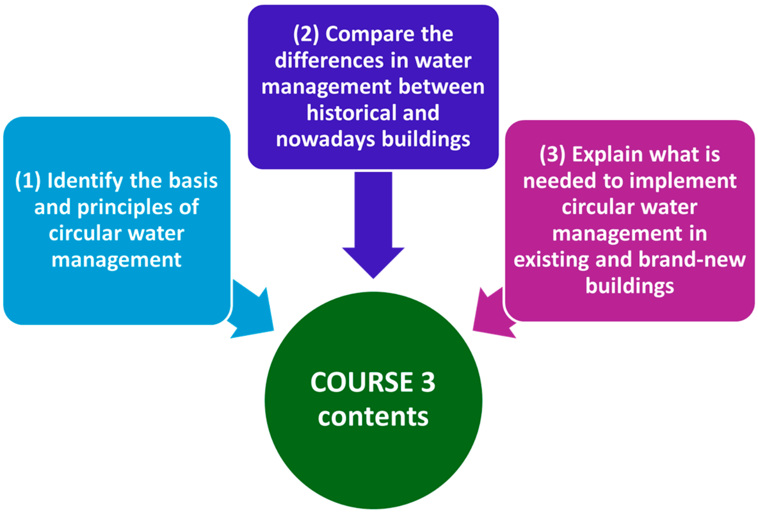

Figure 5. Course 3 learning objectives.

Three modules were defined: Module 1: The Urban Water Cycle and the Importance of Circular Water Management provides an in-depth exploration of the urban water cycle, emphasizing the significance of circular water management in fostering sustainability. Participants delve into the interaction between natural and built environments, examining how urbanization impacts water availability and quality. Real-world case studies are examined to illustrate the application of circular water management principles and their impact on water conservation and quality improvement. Module 2: Rethinking Urban Water Systems through the Circular Economy and Resilience Principles builds on the knowledge acquired in the first module and delves into innovative design strategies for urban water systems that align with circular economy and resilience principles. Participants will engage in comparative study of historical and contemporary water management practices, highlighting the evolution of strategies and technologies. Through interactive sessions, participants are guided on how to incorporate these principles in both existing and new building designs to ensure water efficiency and system resilience. Module 3: Barriers to Implementation of Circular Water Management and Strategies to Overcome Them addresses the challenges and obstacles faced in implementing circular water management in buildings. Participants explore regulatory, financial, and technical barriers, as well as societal and behavioral aspects affecting adoption. Strategies and best practices for overcoming these barriers are discussed, preparing participants to advocate for and implement circular water management in a variety of building contexts.

Course 4: This course focuses on innovative construction materials and their applications in different European countries. The learning objectives for Course 4 are (1) define innovative construction and local materials and their experimental applications in various contexts/countries and EU projects; (2) comprehend the ways in which companies, industries, and other institutions that work with construction materials use innovative construction and local materials; (3) concentrate on the selection and use of innovative, sustainable, and circular construction materials that are locally available; and (4) evaluate the design proposals. By incorporating businesses that are actively involved in the construction industry, the learning objectives were established in accordance with market needs and matched the expectations of the students.

There were two sections to the course. The first sought to establish a common understanding of the following ideas: (i) the connection between materials and environmental sustainability, expanding on recent advancements in ceramic, composite, and street and pavement materials; (ii) the selection of building envelope materials and application of passive interventions (such as solar chimneys, reflective insulation, and phase change materials, or PCMs) for energy conservation; (iii) the relationship between materials and the health of building occupants; and (iv) structural considerations in sustainable construction. Using technical datasheets and other information made available during the lectures, the second section was application-oriented and aimed to create a design proposal based on regional, sustainable circular materials, methods, and creative solutions. In this step, the participants presented and discussed their ideas with the class while working in teams with students from various nations (Figure 6).

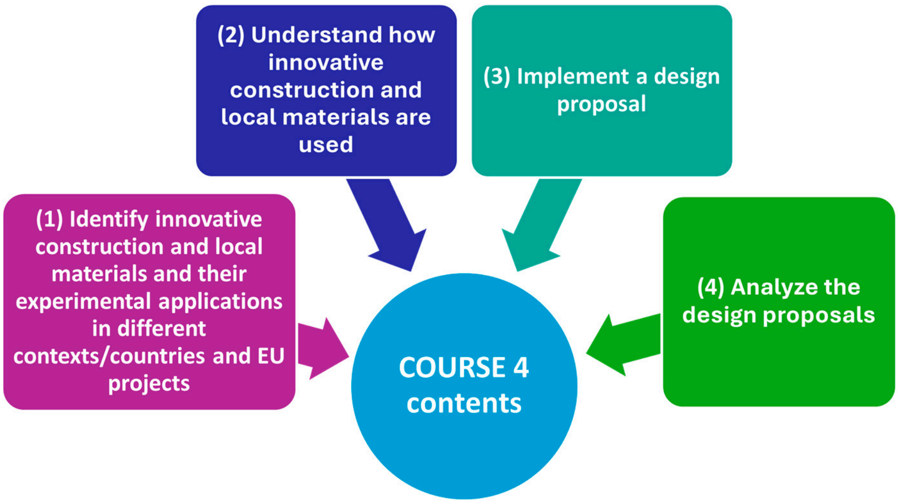

Figure 6. Course 4 learning objectives.

Course 5: The learning objectives are shown in Figure 7. The course covered a diverse range of topics [19], including the design and control of hybrid heating systems incorporating heat pumps, the importance of measurements in buildings, an introduction to building management systems and data collection processes, and the application of data-driven fault detection and diagnostics in buildings systems. It also included a lab focused on data handling in Python and machine learning fundamentals, as well as discussions on structural health monitoring, survey methodologies in historical or urban contexts, and advanced technologies for managing cultural heritage. The course did not focus on a specific case study, but it taught the fundamentals of the main topics of the course, and then the students did some hands-on sessions. The course combined theory with practical application. It focused on engaging students through interactive activities, case studies, and real-world problem-solving, allowing students to apply concepts in a practical context. The flexible structure also allowed for the inclusion of current trends and innovations. This approach fostered deeper understanding, critical thinking, and innovation, aligning with the evolving building sector for sustainability. Interactive lectures promoted active engagement, encouraging students to participate by asking questions. Moreover, a hands-on lab session was conducted using Python programming language for practical learning.

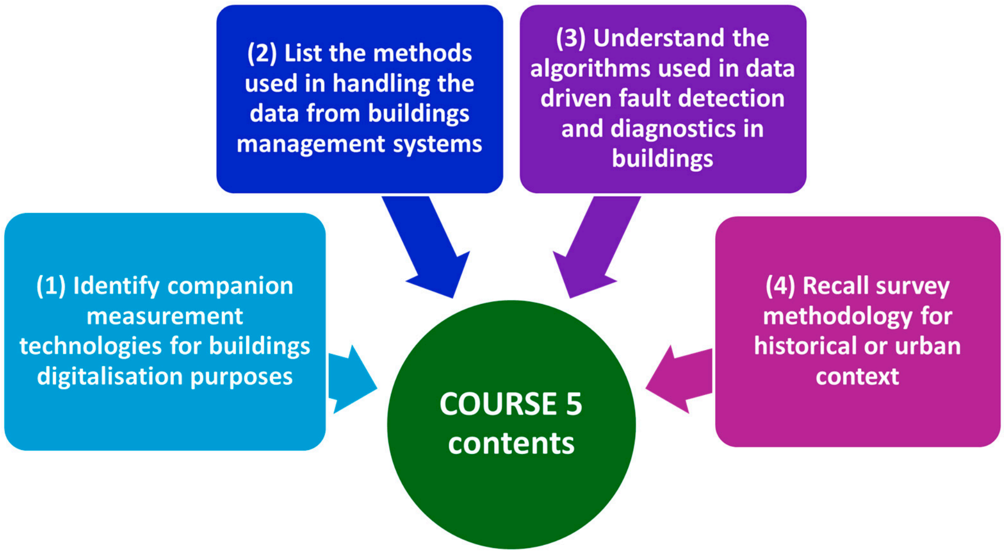

Figure 7. Course 5 learning objectives.

To promote accessibility and inclusivity in the course, several strategies were likely implemented: (1) Flexible learning formats: by providing a combination of mix of online lectures and recorded sessions, the course accommodated students, ensuring that participants with different schedules, learning preferences, or physical limitations were enabled to engage with the material at their own pace; (2) Accessible materials: course content, including lecture slides, notes, and assignments, were made available in accessible formats; (3) Interactive labs: Python for machine learning and data handling, for example, were designed to support learners at various skill levels. These sessions offered and provided hands-on experience, promoting inclusivity and ensuring that students with different backgrounds in technology or engineering could engage effectively.

Course 6: This course concentrated on innovative construction processes through recent experiences with a few European projects and construction and energy organizations. The learning goals for the course are (1) define the concepts of sustainability and health linked to the construction sector and regeneration strategies, as well as their experimental applications in various contexts/countries and EU projects; (2) comprehend how businesses, sectors, and other organizations planned and constructed pertinent structures with sustainability (environmental, social, and economic, with an emphasis on building methods and solutions) and health (wellness); (3) implement the concepts of sustainability and health to buildings; and (4) evaluate what is required for buildings to become sustainable and healthy (Figure 8).

There were two sections to the course. Providing a common knowledge base on the following topics was the main goal of the first section: (i) circularity (EU H2020 "DRIVE 0" Research Project); (ii) deep renovation through add-ons (EU H2020 "Pro-GET-onE" Research Project); (iii) reconstruction-based urban regeneration strategies; (iv) assessment of the building's energy efficiency based on photovoltaic solutions; (v) healthy buildings and sustainable construction solutions; and (vi) prefabrication techniques for building renovation. Two workshops make up the second section, which is application focused. In the first, end-of-life and regeneration proposals for the specific building and structural materials from Course 4 were defined, occupant health and well-being improvements were evaluated, and seismic behavior was simulated. The second task was creating a common checklist that included all the specifications that "sustainable, healthy, and regenerative buildings" should fulfill. Participants collaborated with students from other nations in both sessions, and they presented and debated their ideas with the class.

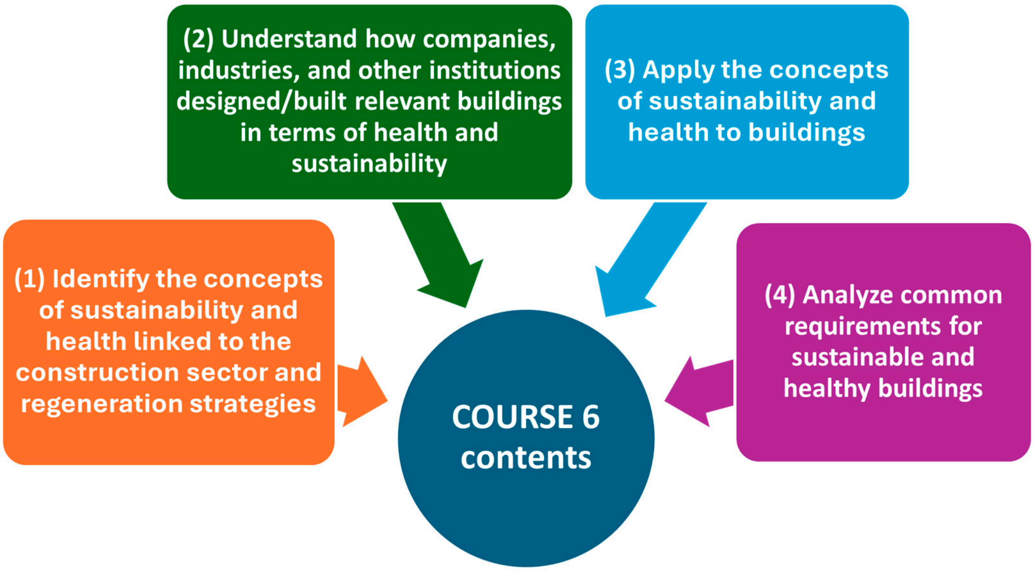

Figure 8. Course 6 learning objectives.

As the pilot training is conceived for graduates working in the construction sector from different European countries (Germany, Greece, Italy, Poland, and Portugal), Courses 4 and 6 curricula were developed to meet the interests of a varied audience with different backgrounds. They proposed valuable experiences from European research projects and practical applications presenting real construction sites and works from companies in the European territory. Trainees have met different case studies in many European countries to have specific results that could be extended to their context/country and critically analyzed to achieve more general and shared knowledge.

The adopted design approach provided shared knowledge for practical implementation in real life and the course [20]. In this case, the application was intended as a workshop/teamwork activity where trainees were asked to put into practice some of the concepts delivered during the first weeks of each course following the methodology of "learning by doing" [21,22]. The instructional materials were prepared following the course division in synchronous and asynchronous activities. The synchronous activities consisted of (a) face-to-face remote lectures, where teachers made presentations and were available for discussion with students using different interaction modalities (round tables, open questions, specific spaces for discussion) and (b) teamwork challenge activities/workshops, where trainers supported the trainees' work, promoting autonomy, cooperation, and critical thinking. This modality allows for active learning and engagement of students, as they were asked to turn on their microphones and collaborate. The asynchronous activities were conceived for individual study at home and consisted of interviews and recorded presentations with final quizzes and assessment activities to test their comprehension. These were connected to the synchronous lectures, so students continued the learning started in virtual classrooms, favoring their engagement.

Course 7: The course focuses on buildings and their construction elements. Firstly, the definition, description, and approach for the circular methodology LCA method was presented. Also, the course participant was introduced to EN 15978 [23] and EN 15804 [24]. Furthermore, the aspects connected with the recycling part of LCA applied to buildings, and construction materials and introduction to the carbon footprint of wooden buildings were considered. Finally, cost analysis as a complementary tool for building LCA analysis was implemented.

To meet the needs of transnational students, the course focused on LCA methodology that is common worldwide, i.e., according to European standards [23]. Furthermore, in the course content were examples from European countries. Also, students could choose the construction material that was analyzed, according to LCA approach, in group work. The methodologies used to identify and prioritize course content were adapted in the international teachers' group. Experts in the field chose the proper methodology for each course topic. The course content was created according to the knowledge of experts in topics: life cycle approach and environmental-LCA methodology [23]; E-LCA for buildings; LCA in energy production, equipment, and distribution; EU and national regulatory framework for LCA for building design; minimum environmental criteria in the Italian context; recycling part of LCA applied to buildings and construction materials; introduction to the carbon footprint of wooden buildings; cost analysis as a complementary tool for building LCA analysis; and simplified LCA applications to construction materials and solutions [25].

The learning objectives were defined and aligned with students' expectations and market demands through a process involving both market consultation and educational expertise. A group of experts, teachers with practical approaches and experience, chose proper learning objectives according to the student expectations and market demands. The learning objectives were defined by aligning both student expectations and the current broader market demands in the field of sustainable building practices. The learning objectives focused on addressing critical issues like LCA methods applied to buildings and energy systems, with a particular focus on biogenic carbon considerations and aspects related to the recycling component of LCA as it applies to construction materials and buildings. Three learning objectives were defined (Figure 9): (1) identify and describe the circular economy method applied to construction; (2) identify the life cycle approach and environmental-LCA methodology; and (3) analyze the LCA methodology applied for buildings and energy systems.

To promote active learning and student engagement, the instructional materials for Course 7 were structured around a practical approach based on real example learning. About 84% were synchronous lectures and exercises, and 16% were asynchronous lectures. During the LCA course, there were case studies in classes where students calculated and presented the results of such investigations. The teachers' team decided that essays would be the best way to conclude that course. After each lecture, students needed to fulfill the test or make an assignment. In the last week of classes, students needed to use the content and knowledge to prepare their own presentations and finally write short essays related to a problematic question, "Can you see any problems with the chosen topic according to circular economy and LCA future development?"

Course 8: The course focuses on upskilling participants so they can navigate the evolving landscape of the construction industry, particularly through the lens of the circular economy. By addressing future challenges in construction, the course emphasizes the importance of developing innovative business models that align with circular economy principles [26]. It broadens participants' view of innovation to include sustainable practices and value creation beyond just technology [27].

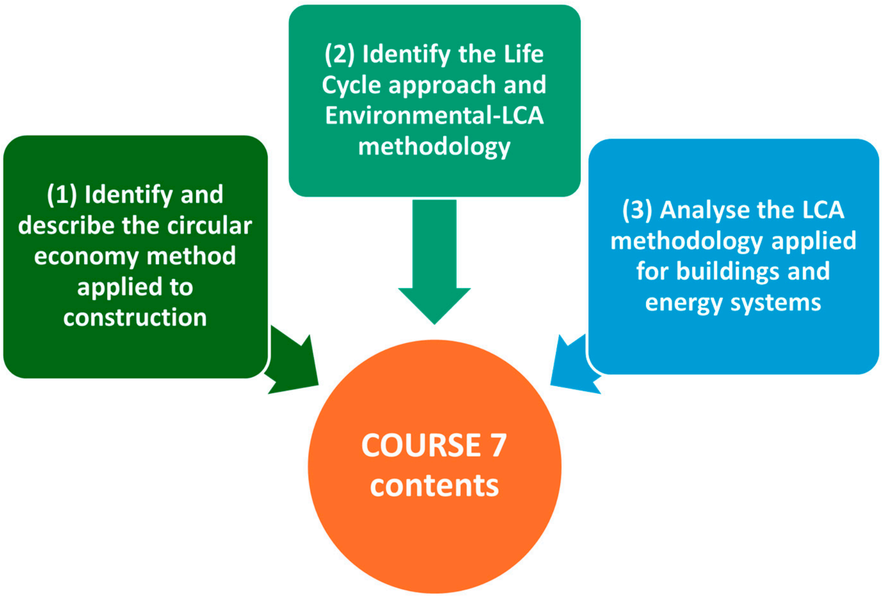

Figure 9. Course 7 learning objectives.

To meet the needs of transnational students, the course focused on responding to what one may call "grand challenges" affecting the construction industry on a global level [28]. This ensured a deeper understanding of the subject matter regardless of geographical location, enabling at the same time students to integrate these challenges into their local context, thus creating a personalized educational journey. To achieve this result, experts in innovation management and the construction industry joined forces to integrate their specialized knowledge, enabling a holistic approach. More specifically, the content was carefully curated by combining the latest trends in the construction industry [28] with the advancements in innovation management [29], ensuring the curriculum remained relevant, forward-thinking, and aligned with industry needs. This blending of expertise aims to prepare participants to meet the challenges of a rapidly evolving industry landscape.

The learning objectives were defined and aligned with students' expectations and market demands through a rigorous process involving both industry consultation and educational expertise. Industry experts and academic professionals collaborated to ensure that the objectives reflected the skills and knowledge most relevant to current and future trends in the construction industry and innovation management. To that end, learning objectives were tailored to equip students with high-demand competencies. This approach ensured the course met academic standards while preparing students for real-world challenges, aligning education with career goals and market demands [30]. The course's instructional design emphasized active, experiential learning with a blend of theory, practical application, and real-world problem-solving [31]. The course's flexible structure integrated current industry trends, fostering deep understanding, critical thinking, and innovation aligned with the dynamic construction industry and circular economy principles.

To promote active learning and student engagement, the instructional materials for Course 8 were structured around an experiential learning approach [30]. Over 70% of the course focused on students becoming problem-finders before problem-solvers, engaging them in real-world scenarios and entrepreneurial projects. This hands-on approach reinforced theory while fostering critical thinking, creativity, and practical problem-solving skills [31].

The course prioritized accessibility and inclusivity through digital strategies, offering materials in various formats such as videos, transcripts, and interactive content to suit diverse learning styles. In parallel, flexible learning paths allowed self-paced progress, while diverse case studies fostered collaboration and reflection. Accessibility features, including closed-captioning, screen reader compatibility, and alternative text, ensured full participation for students with disabilities, creating an equitable, inclusive learning experience.

The course is structured into six modules: (1) Introduction covers the ideation workshop, future challenges in the construction industry and circular economy, and the lean startup methodology; (2) Business Model explores business model basics, the Business Model Navigator framework, the Business Model canvas, and the Value Proposition canvas. All parts of this module are accompanied by case studies; (3) Intellectual Property Management explains intellectual property basics, types of intellectual property, intellectual property management, and the implications of intellectual property on defining a business model; (4) Business Strategy and Innovation focuses on the fundamentals of business strategy, innovation management fundamentals, open strategy, and open innovation, as well as business model innovation; (5) Develop + Protect + Commercialize Model delivers insights into an integrated approach consisting of three streams that lead from the lab to the market; and (6) Presentation Skills enhances effective communication and presentation techniques focusing on innovation.

The six learning objectives outlined in Figure 10 are as follows: (1) create and choose innovative entrepreneurial ideas and business models; (2) analyze and implement business models effectively; (3) gain a foundational understanding of intellectual property and assess its role in generating business models; (4) understand the concepts of open strategy and open innovation and evaluate their applicability in business model creation; (5) learn how to transform technology into a product and subsequently turn the product into a business; and (6) design and create pitch decks to effectively present new business ideas and models.

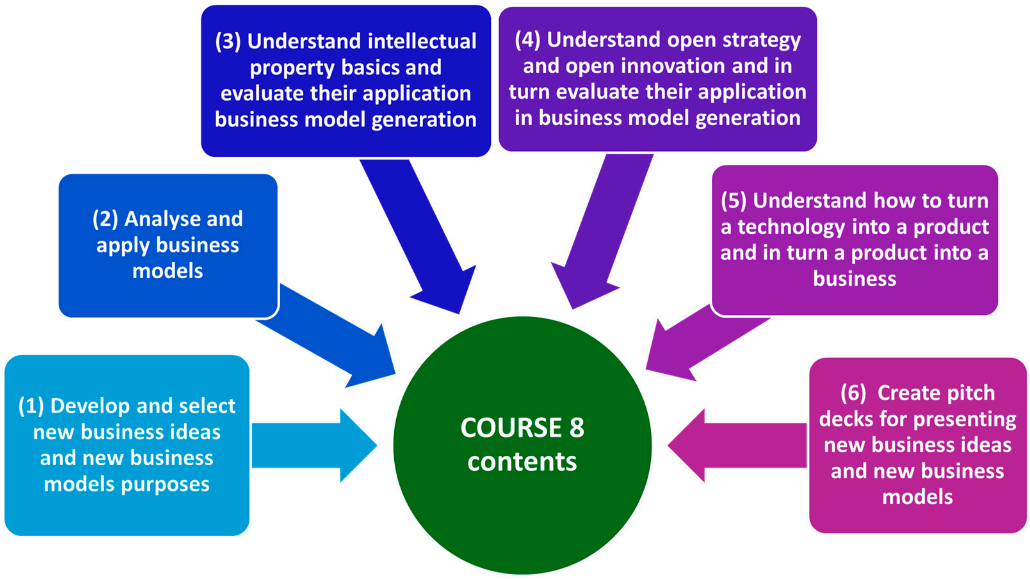

Figure 10. Course 8 learning objectives.

2.3. Technology and Infrastructure

The transnational courses were delivered using Moodle, a widely recognized and robust learning management system (LMS) and Teams/Zoom. By combining those platforms for course management, videoconferencing for real-time engagement, and cloud-based collaboration tools for teamwork, the course ensured that students from diverse geographical and professional backgrounds could collaborate, learn, and apply innovative technologies in the construction industry. These platforms supported both synchronous and asynchronous learning and integration with professionals, making education flexible and accessible for all students. Moodle provided a versatile platform that supported a range of instructional activities, from hosting course materials and assignments to facilitating online discussions and quizzes. Its user-friendly interface and extensive customization options allowed for the seamless integration of various multimedia resources, enhancing the overall learning experience.

Challenges were related to infrastructure, accessibility, engagement, and ensuring smooth coordination across multiple time zones and regions. One of the challenges faced in implementing the technology was ensuring that all users, regardless of their familiarity with Moodle, could effectively navigate and utilize the platform. To overcome this, an experienced Moodle user was made available to assist both students and instructors at any stage of the course. This support included offering guidance on using the platform's features, troubleshooting technical issues, and providing personalized help to ensure that everyone could engage with the course materials smoothly and efficiently. This hands-on assistance was crucial in minimizing disruptions and ensuring a positive learning experience for all participants. Furthermore, in Course 5, Python programming language was a new topic for some students who needed extra support from the teacher.

Regarding assessment methods (Figure 11), the courses utilized typical methods like quizzes but also innovative assessments to measure student progress and performance, heavily emphasizing experiential learning to promote active engagement.

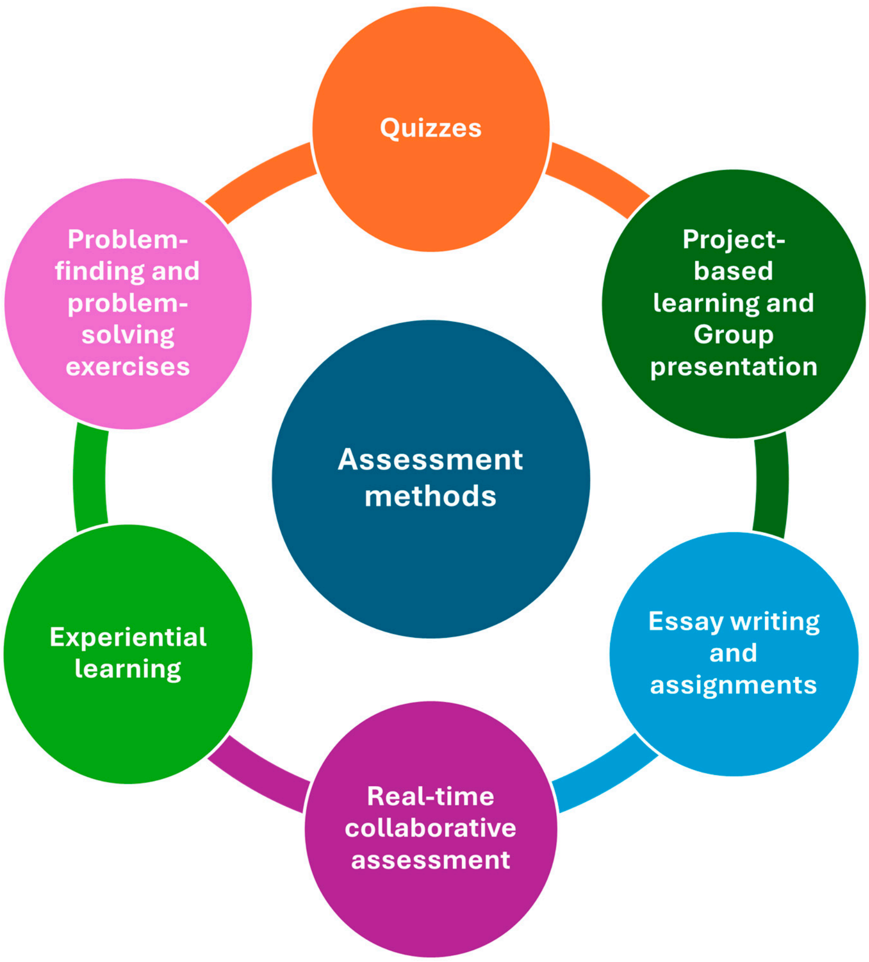

Figure 11. Assessment methods used in BUILD2050 pilot training.

Most courses utilized typical methods like quizzes. In Course 1, the assessment methods were designed to be dynamic and adaptable to a transnational audience. A mix of formative and summative assessments, project-based learning, self-reflection, real-time collaborative assessments, and peer assessment were employed to measure both practical and theoretical knowledge. These methods ensured that students were not only gaining technical skills but also collaborating effectively in a global context, ultimately preparing them for real-world challenges in innovative and transnational construction projects.

In Courses 2, 3, 5, and 7, quizzes were mostly used as assessment methods to measure student progress and performance. In Course 4, some activities were performed on Miro (https://www.miro.com), an online whiteboard tool that allows users to collaborate in real time and asynchronously by creating flowcharts, mind maps, tables, diagrams, etc. In Courses 4, 6, and 8, innovative assessment methods were used, including experiential learning tasks where students developed and pitched their own design proposals or entrepreneurial ideas through video presentations. Additionally, problem-finding and problem-solving exercises were incorporated, requiring students to identify and address real-world challenges. These methods not only measured student understanding and proficiency but also fostered creativity, critical thinking, and practical application of course concepts. A key component of the assessment involved students pitching their own ideas via video presentations. More specifically, students were asked to work in teams to develop their design proposal and present it via video-recorded slideshow presentations. This not only tested their grasp of the material but also their ability to communicate and defend their entrepreneurial ideas effectively and cooperate to provide a shared proposal. These assessments were designed to mirror real-world challenges, providing students with practical experience and a deeper connection to the course content. Course 7 is utilized except quizzes, workshops, group presentations, essay writing, and assignments.

The courses' effectiveness and achievement of learning objectives were assessed using student performance on quizzes, assignments, and projects, along with engagement metrics like participation and completion rates. Qualitative feedback from surveys and reflections was also used to gauge student satisfaction and the alignment with learning goals. A range of metrics was used to assess the course's effectiveness and the achievement of learning objectives (Figure 12). These included student performance metrics, engagement metrics, and satisfaction surveys.

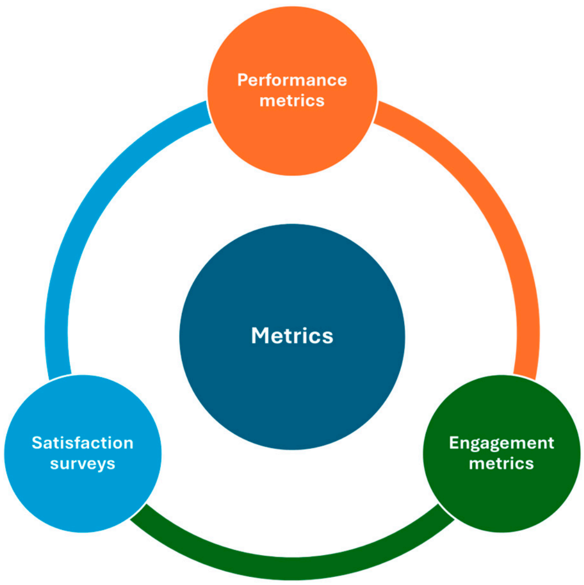

Figure 12. Metrics used to assess a course's effectiveness and achievement of learning objectives.

By gathering data across these various areas, the course leaders could continuously improve the course, ensuring it meets the needs of transnational students while keeping pace and passing this to other course coordinators. Student feedback was collected through a combination of surveys, focus groups, discussions, online tools, and reflective actions where students could express their thoughts on the course structure and content. This feedback provided critical insights into course content, technological platforms, teaching effectiveness, and student engagement. By using this feedback for real-time adjustments during the course and making more comprehensive improvements for future iterations, the course ensured continuous enhancement of the learning experience, aligning with student needs and industry expectations. This iterative process helped maintain the relevance and effectiveness of the course in a transnational, technology-driven educational environment [32].

2.4. Student Support

Support resources for transnational students included access to online help through the platform, personalized assistance, and comprehensive digital resources like video tutorials. These resources ensured that all students, regardless of location, had the necessary support to succeed in the course while supporting an inclusive, flexible, and collaborative learning environment that met the unique challenges of transnational education.

Technical, academic, and emotional support was provided to students through a multifaceted approach. Technical support was available. Academic support was offered through virtual office hours, where students could interact with instructors for guidance, as well as through peer discussions and group work to enhance collaborative learning. Emotional support was facilitated by fostering a supportive community where students have common challenges but not common problems/coursework. A combination of collaborative platforms, virtual team projects, synchronous and asynchronous communication tools, and interactive learning activities were likely adopted to promote student interaction and facilitate collaboration. By integrating peer review systems, structured group roles, and cultural exchange opportunities, the courses ensured that students from different locations and backgrounds could work effectively together. Strategies to promote student interaction and collaboration included discussion, reflection on each other's work, and virtual breakout rooms. These tools fostered a sense of community in the virtual learning environment.

Establishing partnerships and collaborations with international institutions and consortium partners of Project BUILD2050 would have been essential to ensure the successful delivery of the courses. In Courses 1 and 2, the establishment of partnerships and collaborations between international institutions and consortium partners was likely achieved through a combination of strategies. These included joint curriculum development and shared access to resources. The courses likely benefited from partnerships with construction firms, technology providers, and professional organizations (e.g., ASHRAE and Solar Heat Europe), which contributed guest lectures, mentoring opportunities, and real-world case studies. To include practical experiences and widen the research overview, companies, construction firms, and other higher education institutions out of the consortium partners were involved in some of the courses (2, 4, and 6). Additionally, construction site videos and interviews as virtual visits allow the inclusion of trainees from different European countries. Through those collaborations, the courses ensured that students gained a well-rounded, transnational education that aligned with global industry standards.

The international collaboration in Project BUILD2050's Course 1 brought numerous benefits, including access to diverse knowledge, cutting-edge technologies, and real-world case studies. It helped develop students' cross-cultural competencies and exposed them to global industry practices, ultimately enhancing their employability in the construction and technology sectors. However, these benefits were not without challenges, including logistical difficulties, technological disparities, and cultural differences that required careful management and coordination. Balancing these challenges with the advantages of international collaboration ensured that the course could deliver a truly transnational and innovative learning experience [33].

The benefits of international collaboration in implementing the courses included diverse perspectives, enriched content, and broader expertise, which enhanced the learning experience. However, minor challenges, such as managing cultural differences and ensuring consistent communication, were encountered. Despite these challenges, the collaboration ultimately led to a more comprehensive and globally relevant course. Cultural differences were considered and integrated into the course by emphasizing grand global challenges in the construction industry, ensuring the content was universally relevant and accessible across diverse cultural contexts. The course design allowed for the inclusion of local perspectives and practices, encouraging students to bring in their own cultural experiences and insights. This approach not only made the content more relatable but also enriched discussions, fostering a global exchange of ideas. Flexibility in the course structure further accommodated different cultural and regional nuances, ensuring that students from various backgrounds could fully engage and benefit from the material.

3. Results

3.1. Student Feedback

Regarding the students who attended the pilot training of the eight training courses, an average of 66% replied to an anonymous survey carried out at the end of each course to evaluate the implementation of the pedagogical approach. Their feedback on the learning objectives, didactic resources, learning activities, group work, and assessment activities of each training course is shown in Figure 13.

Overall, it can be noted in Figure 13 that the courses' learning objectives, didactic resources, and assessment activities were well-accomplished. However, the learning activities, as well as the group work, need to be improved in this educational context. Nevertheless, in one of the questions of the survey, around 61% of the students stated that the learning process of the training courses was good or excellent, and 37% reported it as reasonable, representing a global rate of 98% of positive feedback on the implementation of the pedagogical approach.

3.2. Teacher Feedback

Regarding teachers who taught in the eight training courses, an average of 79% of these teachers replied to an anonymous survey carried out at the end of each course to report their perception of the application of the student-centered approach and the use of lectures. Their feedback is shown in Figure 14.

Overall, it can be noted in Figure 14 that most teachers of Courses 1, 2, 6, and 7 felt to have fully applied a student-centered approach during its classes, although lectures were often used to teach the course's content. This could reflect why many students who attended these courses pointed out in their survey that some learning activities should have been different. Teachers of Courses 3, 4, 5, and 8 seem to have a realer insight into the insufficient application of a student-centered approach.

Regarding the teaching/learning activities applied in these training courses, from the responses given in other questions of this survey, 40% of the teachers pointed out the lack of time to actively involve students in classroom teaching, and 62% felt that discussions between students on new content are vital for deep understanding. However, 15% believed that students learn more effectively if they work individually than in groups, and 26% felt that to involve students in active learning, the workload was significantly increased. These indicators can be justified by the fact that all classes were taught remotely and by the transnational profile of students attending these courses, which hampers group work.

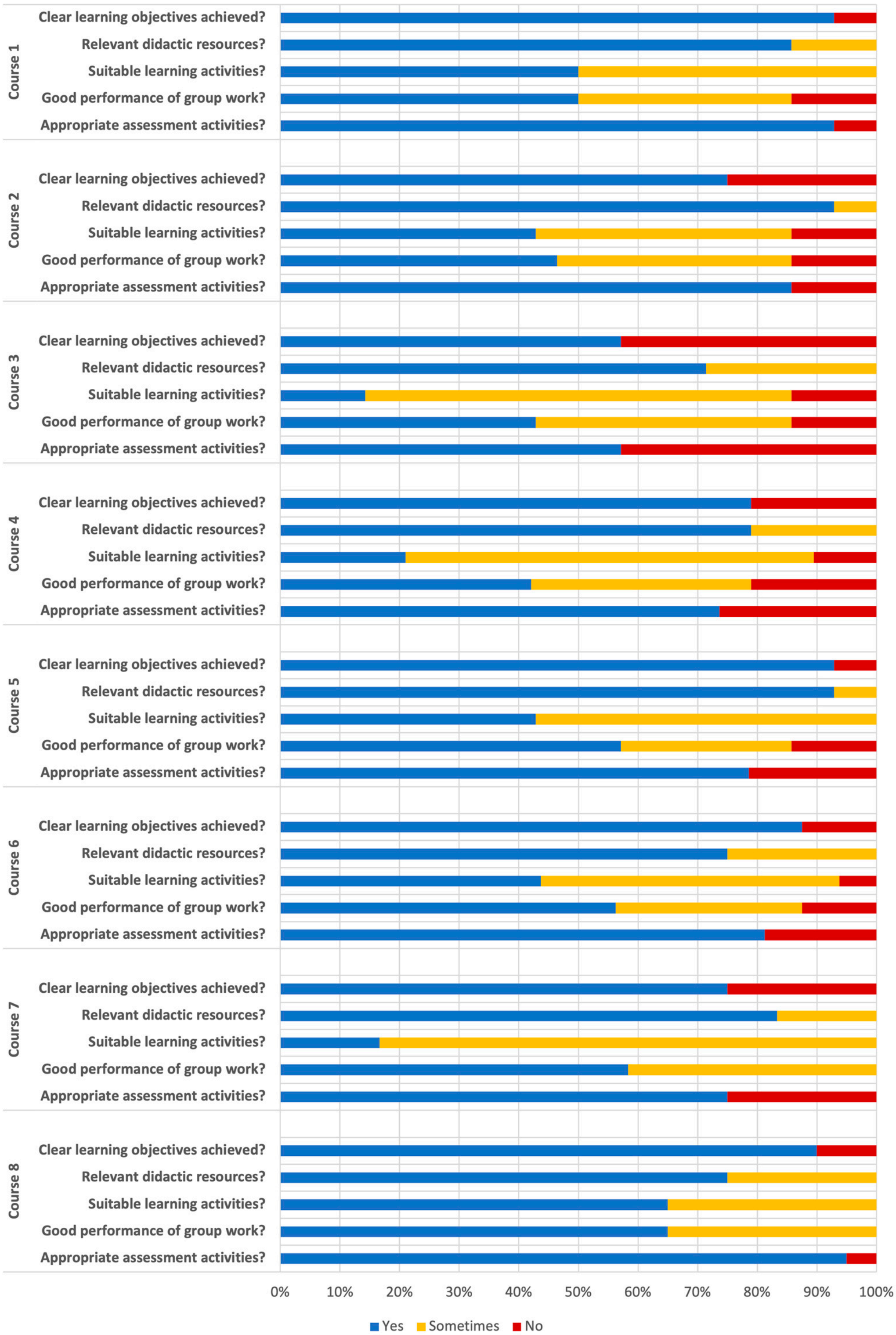

Figure 13. Students' final survey responses for each training course.

3.3. Best Practices and Lessons Learned

Several best practices likely emerged during the development and delivery phases. These practices have contributed to creating an effective and engaging learning environment for a diverse, transnational student body. The challenges that all working teams faced with the content development and the transnational training were numerous. Key lessons learned were identified to define improvements for future editions of the courses.

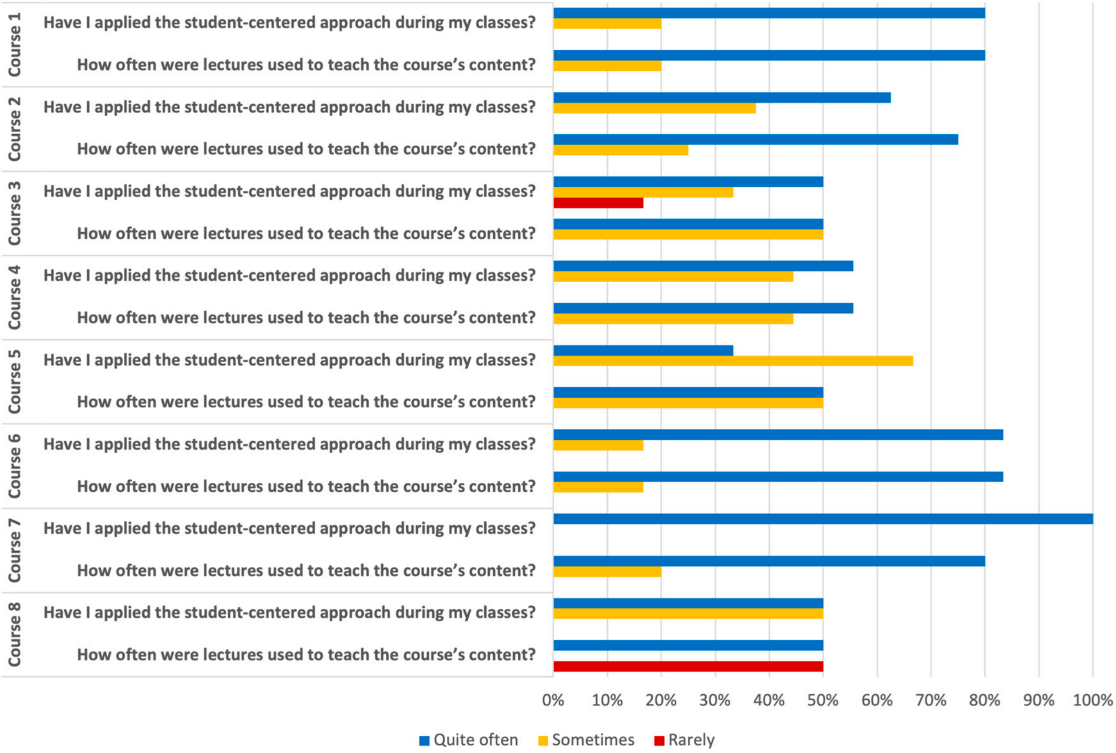

Figure 14. Teachers' final survey responses for each training course.

Course 1: The best practices in the development and delivery of Course 1 focused on creating an inclusive, engaging, and relevant learning experience for transnational students. By emphasizing collaboration, flexibility, technology integration, and continuous improvement, the course was positioned to effectively make a warmup for challenges in the global construction and technology sectors. These practices not only enhanced learning outcomes but also fostered a supportive and enriching educational environment for all participants.

Several valuable lessons likely emerged throughout the development and delivery process. These insights can guide future transnational education initiatives to enhance effectiveness and student engagement. By emphasizing cultural sensitivity, stakeholder collaboration, technological integration, and continuous improvement, educational programs can be better positioned to meet the diverse needs of students and effectively prepare them for the global workforce. These practices not only enhance learning outcomes but also foster a more engaging educational experience for all participants.

To enhance the effectiveness and sustainability of transnational courses like Course 1, several strategic recommendations can be made. These recommendations are designed to address key challenges and leverage best practices identified throughout the course's implementation and include enhancing cultural competence, strengthening stakeholders' engagement, leveraging technology effectively, promoting flexibility in learning, implementing comprehensive support systems, fostering a collaborative learning environment, focusing on continuous improvement, ensuring sustainable practices, aligning with industry standards, and promoting global citizenship. By implementing those recommendations, future transnational courses can improve their effectiveness and sustainability, ultimately leading to enhanced learning outcomes for students.

Course 2: The course included a wide range of topics and many teachers from different disciplines supporting the achievement of learning objectives. One of the best practices was that teachers from various disciplines cooperated from the early beginning to define the thematic modules required to understand the necessary steps to achieve ZEB and PEB toward full decarbonization. This brought together diverse perspectives and ensured a unique learning approach, with each theme contributing to a comprehensive understanding of the steps. Another best practice was that the course contents were divided into synchronous and asynchronous hours, permitting the students who were mostly professionals to organize their available time on a weekly basis. The use of face-to-face lectures with teacher-student effective communication during synchronous sessions and video-recorded presentations, interviews, and other activities during the asynchronous was another best practice. Students had the opportunity to hear interviews with guest speakers from the industry and the market that shared their experiences on various issues, ranging from industry standards to the implementation of new technologies.

Among the main challenges was the coordination of the teachers from various disciplines and the development of the course structure and content focusing on the learning objectives. The contributions to delivering innovative content, without overlapping, was also a challenge. The presence of trainees with different backgrounds from different countries was another challenge for both teachers and students, as in some cases the topics covered required knowledge of the subject to be fully understood by students with different backgrounds. The on-time preparation of the content of all the modules and the collection of inputs were challenges that the working team faced with. The workload of synchronous and asynchronous lectures, interviews, and assessment activities in some cases was a concern considering that most of the students were professionals and had limited time available due to obligations at work.

Improvements for future editions considered include first the customization of lectures and educational materials to assist in the understanding of complex topics and technologies by students with different backgrounds. Furthermore, the workload of some of the modules will be revisited to optimize it and account for the students' different backgrounds.

Course 3: Throughout the execution of Course 3, several challenges emerged, illustrating the complexity of incorporating circular water management into building design and management. However, through collaborative efforts and innovative thinking, solutions were devised to address those challenges. Below are some of the prominent challenges encountered, along with the corresponding solutions: (1) resistance to change; (2) knowledge gap; and (3) technical constraints.

(1) Resistance to change: A significant challenge is the resistance to change from conventional water management practices to more sustainable, circular methods. Participants expressed concerns regarding the feasibility and adaptability of new technologies and practices in real-world scenarios. To overcome this, the course incorporated some real-world case studies demonstrating the successful implementation of circular water management. Additionally, guest speakers from the industry shared their experiences, addressing concerns and highlighting the long-term benefits of adopting sustainable practices.

(2) Knowledge gap: A notable knowledge gap existed among participants regarding the principles of circular economy and their application to water management in buildings, which hindered the learning process initially. Customized learning materials and targeted educational resources were provided to bridge this knowledge gap. Participants engaged in group discussions and hands-on activities to deepen their understanding of the subject matter.

(3) Technical constraints: The integration of new water management technologies into existing buildings posed technical constraints, raising questions about the viability of retrofitting and the associated costs. The course addressed these concerns by exploring various technological options, showcasing adaptable solutions, and discussing financial models and incentives that support the implementation of such solutions in both existing and new structures.

Courses 4 and 6: Some of the best practices were (1) the course division in synchronous and asynchronous hours; (2) content delivery using different modalities (face-to-face lectures, video-recorded presentations, interviews, and teamwork activities), encouraging active learning techniques that comprise simulation to mirror the real environment; (3) workgroup activities in virtual classrooms to foster exchange between international students; (4) proposal of the assessment activities as training, allowing multiple attempts at quizzes and questions to reinforce the acquisition of skills and course content, rather than focusing on the passing grade.

The teachers' team of the courses was numerous and had high geographic diversity. The main challenge was coordinating their contributions to delivering interesting and innovative content, avoiding overlapping and repetitions, and simultaneously following the course structure and learning objectives. Also, the presence of trainees with different backgrounds, affiliations, preparations, and working in different countries was, on the one hand, a valuable opportunity to exchange opinions and, on the other hand, another challenge teachers and students had to face.

The accuracy of planning the courses, the long-lasting phase of coordination, the collection of inputs, and the availability of teachers allow for the definition of valuable and well-organized courses. Additionally, providing adequate time to schedule the courses before they start is essential.

The workload of synchronous and asynchronous lectures, assessment activities, and group work was sometimes excessive in reconciling work deadlines and personal life. In Courses 4 and 6, trainees worked respectively for about 18 and 16 h more than the 25-h planned. This is a relevant aspect to consider for future editions and probably the leading cause of the lack of 100% success. Also, the grant for credits to professional orders (for Italian trainees) was the main driver in gaining participants. However, given the large number of hours and the long period for each course (25 h over 5 consecutive weeks), meeting the minimum frequency percentage (80% and 90% of synchronous hours, respectively, for architects and engineers) was not easy. Then, dividing each course into modules of shorter duration may encourage active participation and grant of professional credits.

Moodle as an LMS was appropriate for uploading, communicating, and delivering the lectures' content and assessment activities. However, that platform turned out to be inefficient for managing the enrollment of external students from higher education institutions/consortium partners, and many administrative and bureaucratic issues had to be managed by researchers and professors involved in BUILD2050 pilot training.

Course 5: The course likely involved input from a range of experts in building digitalization, hybrid energy systems, intelligent energy systems, structural health monitoring in buildings and survey methodologies in heritage buildings, etc. The best practice was its strong interdisciplinary collaboration and the organization of the course into distinct thematic modules, all connected by a central focus on building digitization. This approach not only brought together diverse perspectives but also ensured a cohesive learning experience, with each theme contributing to a comprehensive understanding of the digital transformation in the built environment.

In some cases, the topics covered required an in-depth knowledge of the subject to be fully understood. Thus, lectures of a few hours that covered very complex topics resulted in only a superficial knowledge of the topic. Considering that this project is a transnational initiative, with participants coming from diverse academic backgrounds, one key lesson learned was the need to allocate more time and space for complex and structured topics. This would allow for a deeper and more thorough exploration of each subject. For example, lecture durations could be extended, or complex subjects could be split into multiple sessions to facilitate a more gradual and comprehensive approach.

The incorporation of more interactive elements, such as simulations and practical case studies, would help reinforce complex theoretical concepts. This could enhance student engagement and lead to a better understanding of advanced topics, particularly in areas like data-driven fault detection and structural health monitoring. Moreover, providing additional learning materials, such as pre-recorded videos, reading lists, or supplementary workshops on complex subjects, would help bridge the gap for students with less prior knowledge in certain areas. This would ensure that participants with diverse backgrounds are better supported and can achieve a deeper understanding. Lastly, encouraging students to work on group projects that involve real-world challenges related to building digitalization and energy systems, where teams are composed of students from different countries, could improve the sustainability of the course. This would not only deepen their learning but also foster transnational collaboration, which is a key point of global sustainability projects.

Course 7: The best practices identified in the development and delivery of Course 7 are numerous. As concerns this type of teaching, online learning proves to be the best option for international student classes. Regarding staff, the teaching team is international, while the course content is based on practical examples, and they are different every week. Finally, every student should choose from group or individual work.

It is necessary to give the course participants an opportunity to work in a group or individually. It depends on personal preferences. Also, the synchronous and asynchronous content should be equal to 50/50.

It is necessary to give the course participants an opportunity to work in a group or individually. It depends on personal preferences. Also, the synchronous and asynchronous content should be equal to 50/50. Also, it is necessary to simplify course enrollment and online learning platform registration.

Course 8: The best practices in the development and delivery of the course are (a) an ideation exercise for developing entrepreneurial ideas that fostered the exchange of ideas among participants; (b) an overall experiential learning approach of the course as participants were asked to apply the proposed methodologies to their own professional environments; and (c) a presentation of future trends as a basis for the development of innovative business models.

The key lesson learned is the significant value of collaborative, intercultural group work. While virtual workgroups successfully promoted international exchange, the potential for in-person collaboration in future courses is seen as even more impactful. These findings suggest that future transnational education initiatives should adopt a blended approach, combining flexible delivery methods (such as both synchronous and asynchronous learning), multimodal content (including lectures, videos, and simulations), and opportunities for in-person interdisciplinary teamwork. This approach will foster a more dynamic, inclusive, and engaging learning environment, better equipping students to tackle global challenges.

To improve the effectiveness and sustainability of transnational courses in the future, it is recommended to create cohorts for intensive, in-person courses that emphasize interdisciplinary and multicultural teamwork. This approach would foster a dynamic learning environment where students can directly engage with each other, blending theory with practical applications in a more interactive and collaborative setting. By focusing on these three key elements—interdisciplinary content, multicultural exchange, and hands-on practice—future courses can offer participants a richer educational experience that better prepares them for real-world challenges, ensuring both effectiveness and long-term sustainability (Figure 15).

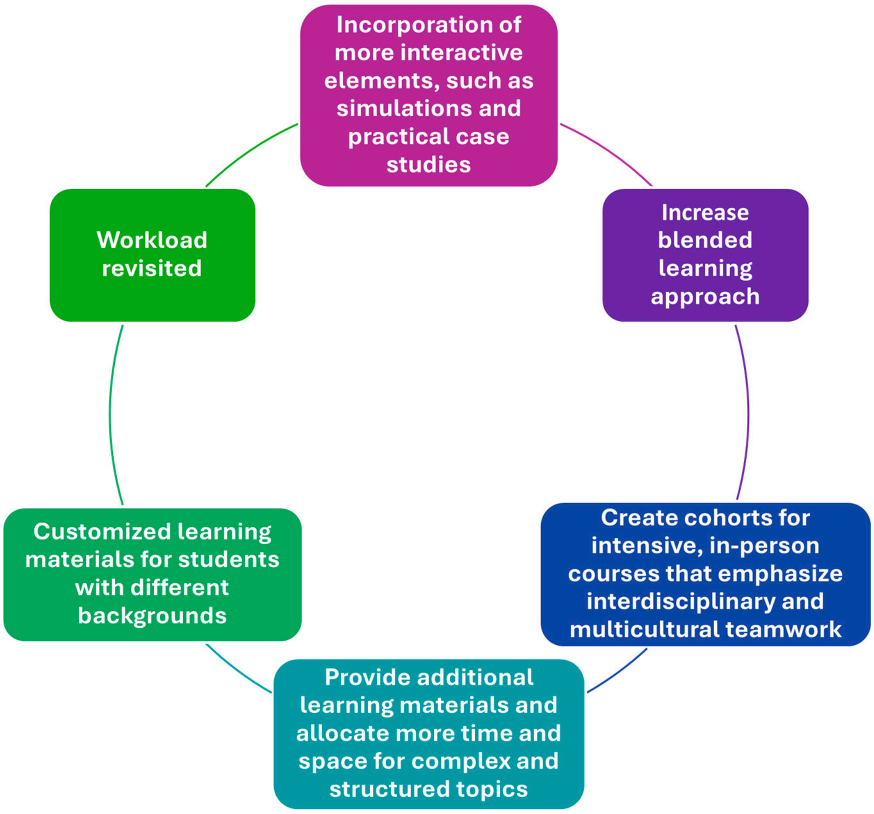

Figure 15. Key elements for future edition of courses.

Furthermore, to enhance student engagement in classroom teaching, several strategies can be adopted. Gamification can be introduced to make learning more dynamic and interactive, such as implementing quizzes, challenges, or team-based competitions that reward students for solving sustainability-related problems or completing group tasks. Additionally, student-led sessions can empower participants to take a more active role by presenting case studies, leading discussions, or conducting mini-lectures on topics of their choice, drawing from their research or professional experiences. Incorporating live industry interaction can further enrich the learning process, with students engaging directly with industry professionals through live Q&A (question-and-answer) sessions, where they can ask questions, discuss current trends, and gain real-world insights. These methods foster active participation, peer learning, and practical understanding, creating a more engaging and impactful educational experience.

4. Conclusions

In this work, results from the efforts to develop transnational training of professionals in the construction sector targeting ZEB and PEB are presented and discussed. The training prepares students for real-world challenges, aligning their education with their career goals and the evolving needs of the building sector. The educational methodology applied is innovative, as it is a set of short courses, which are complementary but autonomous and in which knowledge is made in a circular and complementary way of basic knowledge, with a practical application considering the multidisciplinary nature of the subject.

Teaching and learning activities were defined according to each learning objective established, with an effort to integrate a variety of strategies and methods to facilitate student's learning. The working teams faced challenges related to infrastructure, accessibility, and engagement and ensured smooth coordination across multiple time zones and regions. One challenge was coordinating contributions to delivering interesting and innovative content, avoiding overlapping and repetitions, and simultaneously following the courses' structure and learning objectives. Another challenge was the presence of trainees with different backgrounds, affiliations, preparations, and working in different countries, which was, on the one hand, a valuable opportunity to exchange opinions and, on the other hand, another challenge teachers and students had to face.

Overall, the courses' learning objectives, the didactic resources and the assessment activities were well-accomplished. However, the combined evaluation of the whole procedure using metrics considering the feedback of students and teachers brought some conclusions for future editions of the courses. The learning activities in some courses could be improved, while the workload should be revisited considering the target group's needs. The incorporation of more interactive elements could enhance student engagement and lead to a better understanding of advanced topics. To ensure effective communication among trainees with varying backgrounds, affiliations, and levels of preparation, further enhancement of student involvement in the classroom could be fostered by adding collaborative gamification activities, student-led sessions, and live industry interaction.

Collaborative gamification activities. This type of activity involves teams of students working together to solve challenges or complete tasks in a competitive yet supportive environment, blending learning with interactive elements like point systems or leaderboards. These activities encourage teamwork where progress is tracked through game-like mechanics, promoting engagement and active participation.

Student-led sessions. Allow students to take on the role of instructors for specific topics. They could present case studies, lead discussions, or conduct mini-lectures based on their academic or professional experiences.

Live industry interaction. Arrange live Q&A sessions with industry professionals during classroom teaching. Students can engage directly with experts, ask questions, and discuss current trends or challenges.

Finally, the results of this study provide a robust foundation for practical applications in several areas. For instance, the transnational training methodologies developed here could be directly implemented in professional development programs for construction sector employees, focusing on achieving ZEB and PEB. Additionally, the innovative pedagogical approaches outlined in the courses could be integrated into higher education curricula to enhance student engagement and prepare future professionals for the challenges of sustainable construction. Furthermore, the course content could be adapted in future editions to address the needs of non-technical stakeholders, such as regions and municipalities, by simplifying modules and focusing on practical decision-making and policy implementation strategies.

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