

Article

Training for Sustainable and Healthy Building for 2050 Part 2: Incorporation of New Knowledge and Dissemination for the Sustainability of the Trans-European Training Experience

Susana Lucas ^{1,*}, Maria K. Koukou ^{2,*}, Joanna Aleksiejuk-Gawron ³, Júlia Justino ⁴, Silviano Rafael ⁴, Antonios D. Livieratos ⁵, Nelson Carriço ⁶, John Konstantaras ², Michail Gr. Vrachopoulos ², Luís Coelho ⁴, Anna Chiara Benedetti ⁷, Cecilia Mazzoli ⁷, Annarita Ferrante ⁷, Rossano Scoccia ⁸, Jacopo Famiglietti ⁸, Tomasz Bakoń ³ and Pavlos Tourou ⁹

- ¹ C-MADE—Centre of Materials and Civil Engineering for Sustainability, Barreiro School of Technology, Instituto Politécnico de Setúbal, Rua Américo da Silva Marinho, 2839-001 Lavradio, Portugal
- ² Department of Agricultural Development, Agri-Food and Natural Resources Management, National and Kapodistrian University of Athens, Evripos Campus, 344 00 Psachna, Evia, Greece; johnkonst@uoa.gr (J.K.); mgrvrachop@agro.uoa.gr (M.G.V.)
- ³ Institute of Mechanical Engineering, Warsaw University of Life Sciences—SGGW, Nowoursynowska 166, 00-787 Warsaw, Poland; joanna_aleksiejuk-gawron@sggw.edu.pl (J.A.-G.); tomasz_bakon@sggw.edu.pl (T.B.)
- ⁴ MARE—Marine and Environmental Sciences Centre, Setúbal School of Technology, Instituto Politécnico de Setúbal, Campus do IPS, Estefanilha, 2914-508 Setúbal, Portugal; julia.justino@estsetubal.ips.pt (J.J.); silviano.rafael@estsetubal.ips.pt (S.R.); luis.coelho@estsetubal.ips.pt (L.C.)
- ⁵ Department of Business Administration, National and Kapodistrian University of Athens, Evripidou 14, 105 59 Athens, Greece; alivieratos@ba.uoa.gr
- ⁶ RESILIENCE—Center for Regional Resilience and Sustainability, Barreiro School of Technology, Instituto Politécnico de Setúbal, Rua Américo da Silva Marinho, 2839-001 Lavradio, Portugal; nelson.carriço@estbarreiro.ips.pt
- ⁷ Department of Architecture, University of Bologna, 40136 Bologna, Italy; annac.benedetti@unibo.it (A.C.B.); cecilia.mazzoli@unibo.it (C.M.); annarita.ferrante@unibo.it (A.F.)
- ⁸ Department of Energy, Politecnico di Milano, Via R. Lambruschini 4a, 20156 Milan, Italy; rossano.scoccia@polimi.it (R.S.); jacopo.famiglietti@polimi.it (J.F.)
- ⁹ Institute for Power Systems Technology and Power Mechatronics, Ruhr-University Bochum, Bochum, Universitaetsstrasse 150, 44780, Bochum, Germany; tourou@enesys.ruhr-uni-bochum.de
- * Correspondence: susana.lucas@estbarreiro.ips.pt (S.L.); mkkoukou@agro.uoa.gr (M.K.K.); Tel.: +30-2228021846 (M.K.K.)



Academic Editor: Maohui Luo

Received: 23 March 2025

Revised: 9 April 2025

Accepted: 18 April 2025

Published: 30 April 2025

Citation: Lucas, S.; Koukou, M.K.; Aleksiejuk-Gawron, J.; Justino, J.; Rafael, S.; Livieratos, A.D.; Carriço, N.; Konstantaras, J.; Vrachopoulos, M.G.; Coelho, L.; et al. Training for Sustainable and Healthy Building for 2050 Part 2: Incorporation of New Knowledge and Dissemination for the Sustainability of the Trans-European Training Experience. *Buildings* **2025**, *15*, 1512. <https://doi.org/10.3390/buildings15091512>

Copyright: © 2025 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

Abstract: This paper presents the innovative key knowledge breakthroughs achieved as one of the results of the BUILD2050 Erasmus+ project, focused on its contribution to advancing climate-resilient building engineering education and practice. In a recent work, the new methodologies applied in the BUILD2050 initiative were presented. This work discusses the incorporation of new knowledge in the courses and dissemination for the sustainability of the trans-European training experience. The challenge faced by the European Union for 2050 is achieving climate neutrality and decarbonization across all economic sectors, including the significantly impactful construction sector. To achieve this objective, it is necessary to develop technologies in an integrated way, following a holistic approach appropriately adapted to climatic conditions, cultural contexts, and natural resource availability through circular economy methodologies. To this end, it is necessary to develop innovative training methods with multidisciplinary content, incorporating a transnational perspective and scope, enabling continuous updating through learning cycles. These study cycles could be shorter and more complementary, allowing greater flexibility in knowledge acquisition while also enabling the creation of specialized training programs similar to those currently available. The BUILD2050 project has developed a transformative educational framework comprising eight comprehensive “Pilot Training” courses to address the critical challenge of integrating sustainability and circularity concepts

into educational curricula at all levels, building engineering training and professional development. Addressing this gap is essential for transforming the construction sector and achieving global climate goals. The results of the BUILD2050 project demonstrate the potential of structured, trans-European training experiences to enhance professional competencies and support the transition to climate-neutral construction. Moving forward, widespread adoption and continuous dissemination of these educational advancements will be vital in ensuring a sustainable built environment by 2050.

Keywords: new knowledge; dissemination; transnational training; sustainable buildings; ZEB; PEB

1. Introduction

At present, it is estimated that the building sector is one of the main contributors to greenhouse gas (GHG) emissions, primarily due to fossil fuel usage during its operational phase. The buildings sector is a key contributor to GHG emissions in the EU, representing 34% of energy-related emissions in 2022, as reported by the European Environment Agency [1]. Even so, inefficient building systems waste a significant portion of the energy provided to buildings. Future development must include both the problems and opportunities presented by technical, environmental, and sociological developments [2]. The growing focus on sustainability is encouraging the construction industry to design more sustainable buildings [3]. This is challenging because a variety of factors affect building energy performance, such as ambient weather conditions, building structure and characteristics, the operation of building components such as heating, ventilation and air-conditioning (HVAC) and lighting systems, occupancy, and occupant's behaviour. This complex condition makes it extremely difficult to precisely anticipate building energy use [4].

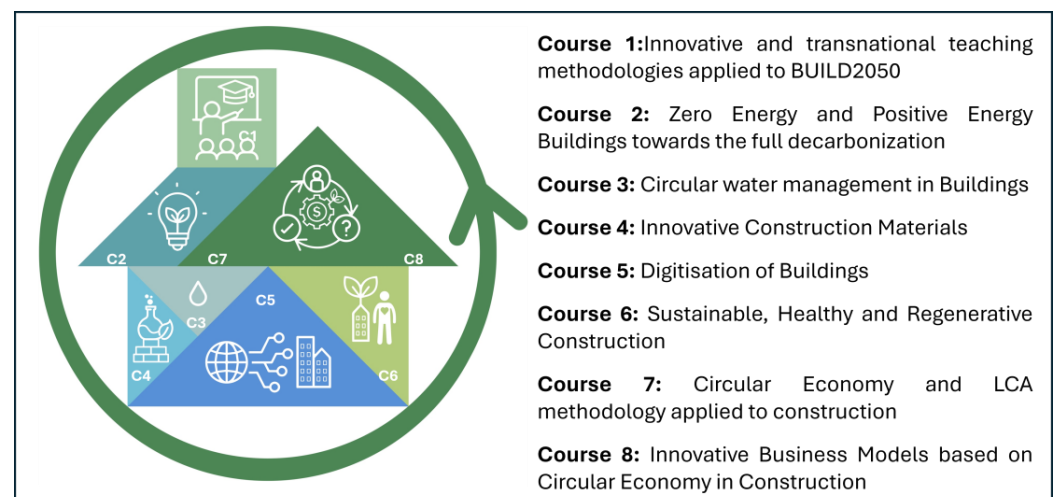
According to the new regulations, all new buildings shall be zero-emission by 2030, and the whole EU building stock should be zero-emission by 2050 [5,6]. All residential structures in the EU will be obliged to reach at least an E energy efficiency rating beginning in January 2030, with a D rating or above by January 2033. These new guidelines are a component of the Minimum Energy Performance Standards (MEPS). The revised Energy Performance of Buildings Directive (EU/2024/1275) aims to accelerate the renovation of the EU's least efficient buildings. Looking ahead, the MEPS demands that all buildings attain an A or B energy efficiency grade by 2040, consistent with the wider aim of zero-emission buildings by 2050.

Sustainable building is not hampered by a lack of technologies and evaluation methods but rather by the organizational and procedural challenges that come with implementing new methods. New technologies are rejected because they necessitate process modifications that carry risks and unanticipated costs [7]. Another study [8] suggests that the most important driving forces behind sustainable design and construction were energy conservation, improved indoor environmental quality, environmental/resource conservation, and waste reduction. Furthermore, the most important impediments to sustainable design and construction were the project's initial cost premium, extended payback periods from sustainable techniques, a preference for current practices, and subcontractors' poor knowledge and abilities [8].

Despite the urgent need to fight climate change and be climate-neutral by 2050, as outlined by the European Commission through the European Green Deal [9], in the field of engineering education, there is a significant gap in climate change design knowledge, skills, and competencies for both students and educators. As remarked by the Intergovernmental Panel on Climate Change (IPCC) [10], widespread dissemination of the concepts behind

sustainability and circularity within educational environments (before graduation, for students at different levels, as well as after graduation, for professionals) is one of the biggest challenges in the construction sector.

With the aim of contributing to filling this gap, the “BUILD2050” Erasmus+ Project developed a series of eight training Courses covering the most significant topics of sustainable construction, as shown in Figure 1a [11]. BUILD2050 is innovative because it aims to create a network of highly qualified professionals capable of representing different skills specialized in their field and for their specific climatic and cultural context but also informed and aware of the different possibilities offered by other countries. The cross-disciplinary knowledge thus achieved by course participants represents an essential resource for connecting indispensable information to implement in-practice interventions to achieve Zero Energy Buildings (ZEB) and Positive Energy Buildings (PEB) targets. A recent work [11] presents and discusses the pedagogical approach used to develop the courses’ contents, students’ support, the results obtained from the evaluation carried out after the pilot training of the eight training courses, and best practices and lessons learned.



(a)



(b)

Figure 1. (a): List of the training courses developed in BUILD2050. (b): University Partners in BUILD2050.

Before the eight training courses began, a structured 5-step pedagogical framework was developed to prepare and align course leaders and their team teachers with the student-centred approach [11]. This framework involved defining clear learning objectives, designing the course structure, planning engaging learning activities, developing effective didactic resources, and implementing and evaluating the overall approach. At the end of each training course, participants completed an anonymous survey to provide feedback on the application of this pedagogical method. The responses showed that the learning objectives, didactic, didactic resources and assessment were successfully accomplished. However, there was a clear need for improvement in learning activities and group work to enhance the overall effectiveness of the courses. Also, regarding the 202 evaluated students who attended the courses, an overall 65% success rate was achieved.

Specific details about the courses and the participating organizations illustrated in Figure 1b can be found in [11].

This work describes the incorporation of new knowledge and dissemination for the sustainability of the trans-European training experience. New knowledge is presented in the following points: (1) relevance and innovation, (2) practical applications, and (3) industry relevance. Dissemination is presented in the following points: (1) dissemination strategy, (2) communication channels, and (3) engagement with stakeholders.

Based on the pillars of the BUILD2050 project, it could be stated that current models of continuous and simultaneous training in different areas of knowledge in a compartmentalized way can lead to difficulties in deepening knowledge and producing excessive work simultaneously. Therefore, the BUILD2050 approach proposes transdisciplinary study cycles that are more effective and complementary, thus allowing the optimization of resources and flexibility in the acquisition of transversal knowledge as well as—in the same way as currently existing ones—the creation of specialized training offers. According to the author's knowledge, there is a lack of international examples of similar courses. Some Universities offer short-term online courses for professionals and leaders. Also, summer schools, mostly for students, on similar topics are available stationary. Those two groups are different and offer knowledge only to professionals or students. BUILD2050 courses offer the knowledge that is prepared for both groups and in an interdisciplinary context.

2. New Knowledge in BUILD2050

Novel concepts, theories, or practices were introduced in the course contents, as well as emerging topics or trends relevant to the field. Real-world examples, case studies, or practical applications were incorporated to reinforce learning. Finally, the direct involvement of representatives from the market, companies, and organizations and the alignment of the course contents with industry standards and practices were some of the targets from the beginning of the project, as discussed in the following sections.

2.1. Relevance and Innovation

In Course 1, a first overview of knowledge about the buildings was attempted and served as a warming up to the next courses of the project. The most innovative element (Figure 2) was the live streaming in some interviews with Municipalities such as Moita Municipality, Guarda Municipality, and Politécnico da Guarda (IPGuarda), where there was direct interaction between trainees and technical staff of Municipalities. Contents were selected and addressed according to the needs that the municipalities presented in relation to the decarbonization of their buildings [12]. The technical staff of municipalities addressed issues that they consider to be challenging for the decarbonization of their buildings [13]. New knowledge is also presented in activities to renovate houses with high energy poverty [14] and in solutions for buildings presented by LNEG (National

Laboratory of Energy and Geology) and ADENE (Portuguese Energy Agency). All these entities contributed their views but also posed challenges for the trainees.

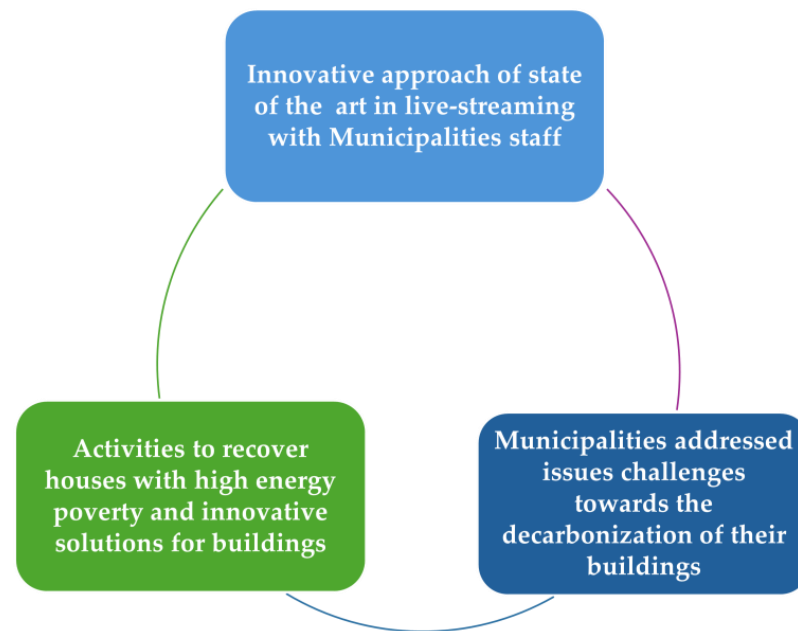


Figure 2. New knowledge in Course 1.

In Course 2, all course modules were initially introduced by academic experts with extensive experience in research projects who are at the forefront of research and innovation in their field. After the academic instructors, participants viewed interviews by industry experts, including constructors, engineers, and technology companies, which aided in the educational process by adding their understanding of the systems and technologies, explaining complex issues using simpler communication language, and merging the gap between directives and standard industry practices. New knowledge was introduced at various levels related to the building's operation (Figure 3). The latest trends in indoor environmental quality were discussed, including ventilation and lighting, and international building standards were considered [15]. Current trends in technologies for heating, cooling, and domestic hot water (DHW) production were also presented. The importance of exploiting Renewable Energy Sources (RES) to cover building needs was highlighted [16]. The electrification of buildings in the future is a fact, allowing the use of solar photovoltaic (PV) energy as the main source of energy. However, for the electrical energy produced by PV systems to be effective, it is necessary to reduce energy consumption by implementing energy efficiency solutions, improving the energy behaviour of thermal envelopes, including the use of passive air conditioning solutions, and developing more efficient active heating, cooling and DHW production systems, namely based on heat pumps (HPs). It also discussed how to increase energy efficiency and indoor thermal comfort in buildings with passive solutions. Innovative materials and techniques were considered, depending on building type, structural characteristics, and climate conditions: super-insulating materials, vacuum insulation panels (VIPs) with thermal conductivity, multi-layer thermo-reflective systems, etc. Furthermore, the use of high-capacity materials and phase change materials (PCM) to shift peak thermal loads and increase energy storage and advanced facade systems (Trombe-wall system, ventilated facade, green roof, and façade, cool roof) that allow the reduction of energy needs for cooling, especially in warm climate locations were analyzed.

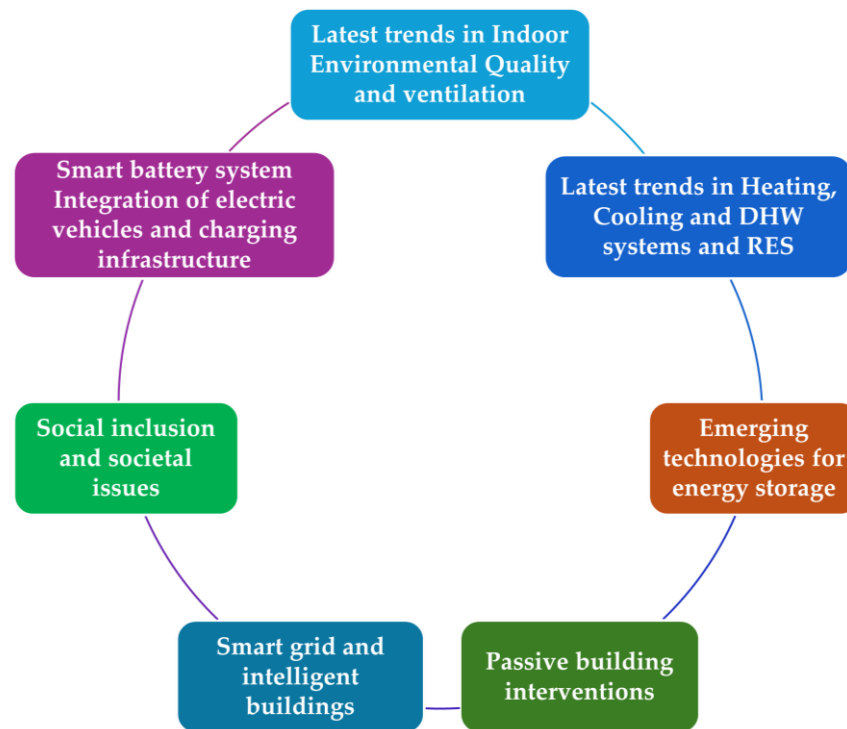


Figure 3. New knowledge in Course 2.

The course also introduced the participants to emerging technologies for energy storage, including new battery technologies and thermal energy storage with phase change materials [17,18]. Emerging technologies for energy storage that were developed in two research projects were presented. The problem that the EU Horizon 2020 Project TESSe2b project [17] proposed to solve was the optimization of renewable energy use, developing one of the most advantageous solutions to correct the mismatch that usually occurs between energy supply and demand in residential buildings, which is the use of optimized storage systems. This contributes to increasing the share of RES for heating, cooling, and DHW in buildings, increasing the energy efficiency of the systems, and increasing the flexibility of the energy grids. Moreover, the SCORES EU Horizon 2020 Project [18] is perfectly aligned with the widespread implementation of smart grids and their corresponding technology.

It was explained why it is necessary to use short-term and/or seasonal hybrid electrical and thermal storage systems to overcome the problem of mismatching the energy sources and energy consumption, to integrate the energy systems of various types of buildings in microgrids or grids at the neighbourhood or district levels, and to develop and implement intelligent and predictive control systems to dynamically optimize the operation of energy systems, preparing them in advance for the following periods of energy use.

The goals of 100% RES in buildings by 2050 require us to develop solutions that are easy and quick to install, usually based on prefabricated renovation kits for the constructive parts of the buildings and for the energy systems. In the near future, it is expected to see important developments in highly efficient HP systems for heating, cooling and DHW production and their integration with other parts of the energy systems such as new refrigerant fluids, more environmentally friendly and more efficient, new solutions for geothermal heat pumps, including new solutions for drilling and installing borehole heat exchangers and integration of HVAC system with dynamic thermal envelopes of the buildings. Energy management systems in buildings with (i) solar thermal power and Phase Change Material (PCM) thermal energy storage and (ii) integration of electric vehicles and charging infrastructure within the built environment and grid were also discussed. Furthermore, the emerging

issues of social inclusion and societal issues like technological illiteracy and energy poverty were commented on, and measures for mitigation and protection of such social groups against the effects of the ongoing rapid technological advancement were analyzed. The smart readiness indicator (SRI) was introduced, and its importance for fifth-generation networks and machine-to-machine communication was explained.

In Course 3, the contents were structured to present traditional and innovative urban water systems, exploring both centralized and decentralized management strategies [19,20]. In 2050, buildings incorporating circular water management will likely feature advanced water recycling systems, innovative rainwater harvesting techniques, and intelligent water monitoring and control systems. These buildings will be designed to optimize water use, minimize wastewater generation, and maximize the reuse of treated water for non-potable applications such as irrigation, toilet flushing, and cooling systems. Following those trends, topics covered the separation of grey and black water [21], the integration of rainwater harvesting with nature-based solutions [22], and strategies for overcoming regulatory and technological barriers (Figure 4). Participants also examined the evolution of water management in buildings, from historical practices to cutting-edge solutions, and engaged with industry professionals to discuss real-world challenges and applications.

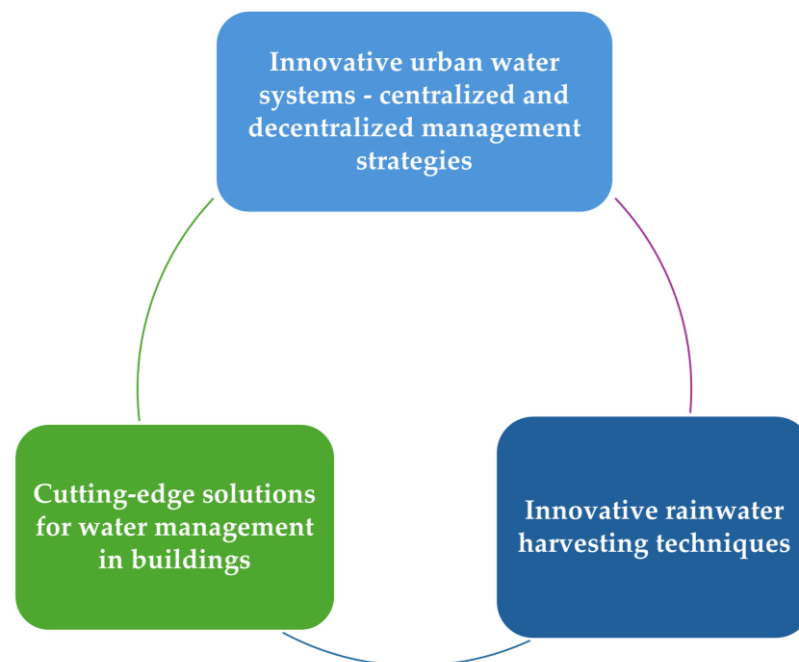


Figure 4. New knowledge in Course 3.

Course 4 focused on innovative construction materials and their applications in different cultural and climatic contexts [11]. It was structured to include lectures presenting traditional and innovative building materials, mainly analyzing their requirements for environmental sustainability and circularity in terms of carbon emissions and potential for reuse and recycling. This issue was addressed through the involvement of the project's partners and associated partners located throughout Europe, with a focus on the implementation of local construction techniques and materials. In fact, great importance was given to sustainability intended as the optimization of resources for new buildings or deep renovation of existing heritage, limiting the waste of structural and insulating materials that are surplus to the performance requirements of local regulations and limiting the carbon emissions given by the transport of materials coming from distant geographical contexts.

In order to make a selection of the topics currently most important to the construction industry, the partners and associate partners involved in Course 4 were asked to propose a

topic of particular relevance according to their experience and present both its theoretical aspects related to the nature and performance of materials, and practical aspects, related to the potential application of materials, through the presentation of real case studies (Figure 5). These pilot cases included innovative materials currently under investigation, such as the following: innovative technologies for lightweight architecture by the Italian University of Catania under the Project “eWAS—An Early Warning System for Cultural Heritage” (PON ARS01–00926) [23]; innovative materials for paving and streets by the DICAM of UNIBO; innovative ceramic tiles by the Italian Association Confindustria Ceramica [24]; innovative approaches to design, construction materials and techniques proposed by the Portuguese cooperative Biovilla [25], the Spanish design studio PMMT Architects [26], and the Portuguese company Isocor [27].

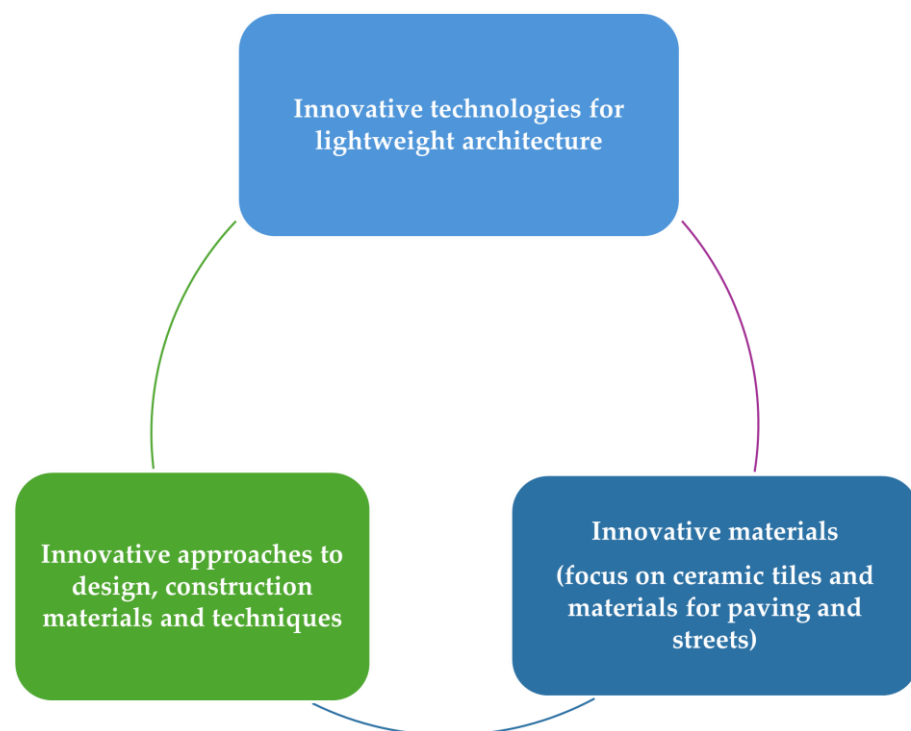


Figure 5. New knowledge in Course 4.

Course 5 was structured to include lectures about measurements in buildings, focusing on the transition from traditional Building Management Systems (BMS) to smart building systems, which are currently playing a fundamental role in the improvement of building energy efficiency (real-time data and predictive analysis). Adaptive HVAC control solutions were explored, from the widely implemented rule-based methods dominating the market to the cutting-edge Model Predictive Control (MPC) systems [28]. Concerning intelligent energy systems, the main innovative and emerging topics that were discussed during the lectures addressed home automation, digital twins, and smart grids (Figure 6). Regarding data-driven fault detection and diagnostics in buildings, the course showcased innovative methodologies to identify and address inefficiencies in operations, representing a shift toward more proactive building management strategies. Different types of automated fault detection were presented, from the most available rule-based algorithms to the model-based and data-driven/black-box ones. The module on structural health monitoring in buildings introduced tools and frameworks for the continuous assessment of structural integrity in buildings, also proposing new ideas for future applications. In the lecture about survey methodologies in heritage buildings, modern, non-invasive techniques for preserving and analyzing historical structures within urban contexts were presented [29].

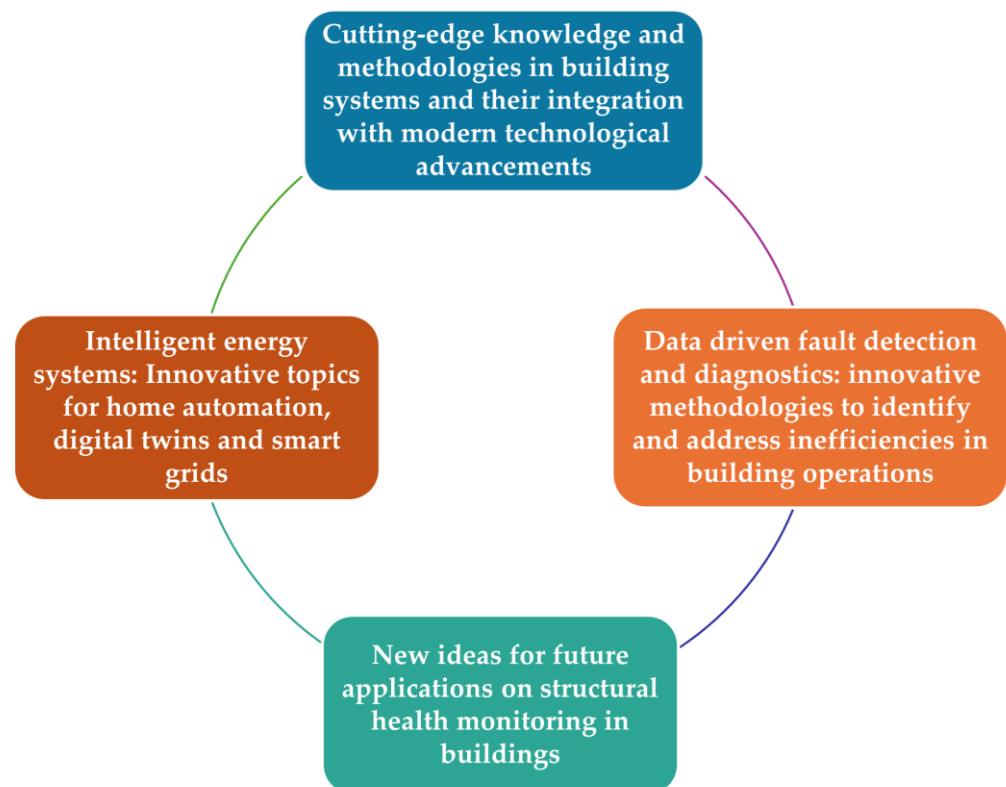


Figure 6. New knowledge in Course 5.

The course introduced and explored cutting-edge knowledge and methodologies in building systems and their integration with modern technological advancements. It was designed to deliver new insights through lectures, case studies, and materials developed specifically to highlight emerging trends and innovative practices. High importance was given to buildings in modern society and their environmental impact, underlining how measurements play a vital role in the whole building life cycle, from the construction, operation, and end of life of a building. The course involved European project partners and associate partners (i.e., SGGW, LSI system, IPS, UNIBO, and La Sapienza).

Course 6 focused on innovative construction techniques through recent experience with some European research projects and construction and energy companies [11]. The course was organized to address the topic of deep renovation of the built heritage according to a sustainable and circular approach, in line with the decarbonization objectives imposed by the European Union (EU), through the presentation of research projects and works recently carried out by academic institutions and industry. This choice assumed that a dual vision—theoretical and practical—of the technical construction aspects of regeneration strategies is fundamental to fully understanding the potential and criticalities of the traditional building systems available on the market and the innovative ones currently under investigation. Great attention was given to the theme of the reversibility of interventions (in terms of Design for Disassembly and Design for Adaptability), environmental impact (in terms of Embodied Carbon and Embodied Energy), and potential for reuse/repair/recycling components during the building lifecycle.

Controlling these parameters during the design process, which involves iterative cycles of design, analysis, verification, and subsequent adjustments, can be facilitated using Building Information Modelling (BIM) tools. For example, through these tools, it is possible to speed up the process of calculating the quantities of materials for the development of LCA analysis and facilitate the process of evaluating the level of reversibility and circularity of building components. A design approach that follows these principles contributes to

maximizing the recovery and reuse of building materials, minimizing waste generation and, consequently, minimizing embodied carbon.

In order to structure the course with the themes currently most relevant for the construction industry, partners and associate partners involved in Course 6 were asked to propose a topic of particular relevance according to their experience: once identified this topic, they had to present its theoretical aspects, related to the approaches and methods adopted, as well as its practical aspects, associated with the implementation of specific building components and construction techniques, through the presentation of real case studies. Indeed, lectures included innovative systems for new construction and renovation of buildings (Figure 7), such as the following: circular prefab solutions for energy retrofit of historic buildings through an innovative plug play façade system developed by the Italian company ALIVA–IVAS Group [30], in cooperation with UNIBO, under the EU Horizon 2020 Project “DRIVE 0—Driving decarbonization of the EU building stock by enhancing a consumer centred and locally based circular renovation process” (G.A. No. 841850) [31]; an integrated model of prefabricated steel and timber housing module called “Integhro” for energy-efficient new buildings, developed by the Department of Architecture of UNIBO; the innovative “GET” system for energy and seismic retrofit of existing recent buildings through the implementation of a steel exoskeleton, able meanwhile to add extra spaces, under the EU Horizon 2020 Project “Pro-GET-onE—Proactive synergy of inteGrated Efficient Technologies on buildings’ Envelopes” (G.A. No. 723747) [32] coordinated by UNIBO; innovative nature-based solutions for sustainable buildings presented by IPS; high-efficient prefabricated systems for wall partitions implemented by the German company Vonovia [33]; examples of best practices and technical solutions for healthy and comfortable spaces in terms of installations and domotics by Portuguese company T&T [34], building-integrated photovoltaic technology and applications by RUB, industrialized components by FRAC-TUS [35], healthy materials and systems by the Spanish company PMMT Architects [26], and the Portuguese company JSJ Structural Engineering [36].

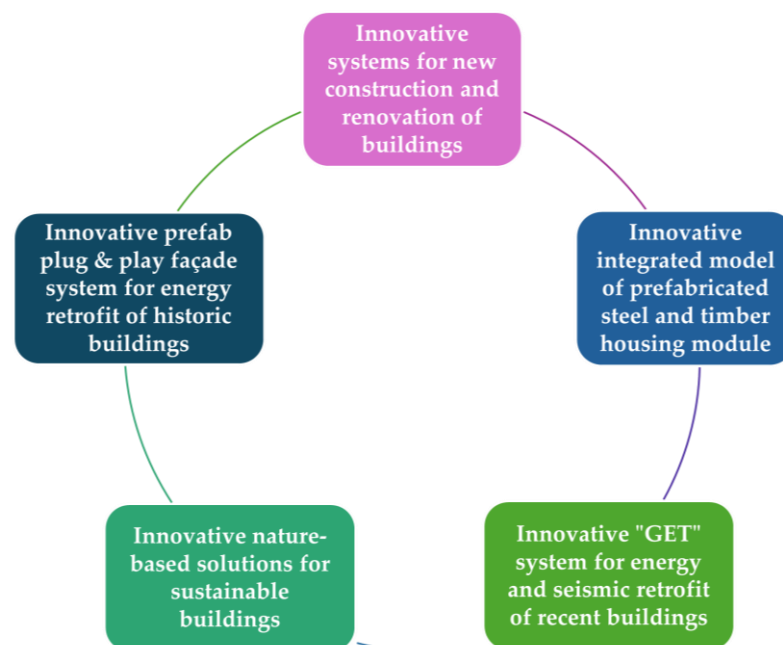


Figure 7. New knowledge in Course 6.

Course 7 centered on the application of circular economy principles and process-based Life Cycle Assessment (LCA) methodology to buildings and their construction elements. The course begins with an exploration of the definition, description, and approach of the

circular methodology within the LCA framework. Participants were also introduced to relevant European standards, specifically EN 15978 [37] and EN 15804 [38], which guide LCA practices for buildings.

The course content introduced novel concepts, theories, and practices, particularly in LCA, which remains a relatively new concept (Figure 8). This subject was specifically selected due to its strong alignment with the overarching objective of the BUILD2050 project, encompassing all previously mentioned topics. The incorporation of emerging topics and trends pertinent to the field was evident, notably in the areas of regulatory frameworks for LCA, recycling within LCA, and the crucial cost analysis components [39]. These emerging topics were identified and integrated through collaborative efforts during remote meetings with a team of international experts under the guidance of a designated course leader who compiled the final curriculum. A comprehensive overview is provided on the application of the LCA method to buildings and energy systems, with a particular focus on biogenic carbon considerations. The course further delves into aspects related to the recycling component of LCA as it applies to construction materials and buildings. An introduction to the carbon footprint of wooden buildings is included to highlight sustainable practices in construction. Lastly, cost analysis is incorporated as a complementary tool, augmenting traditional LCA analyses to provide a holistic understanding of the economic implications of sustainable building practices. Additional focal areas included the Minimum Environmental Criteria within the Italian context, the integration of recycling in LCA applied to buildings and construction materials, an introduction to the carbon footprint of wooden buildings, cost analysis as a supplementary tool for building LCA analysis, and simplified LCA applications for construction materials and solutions.

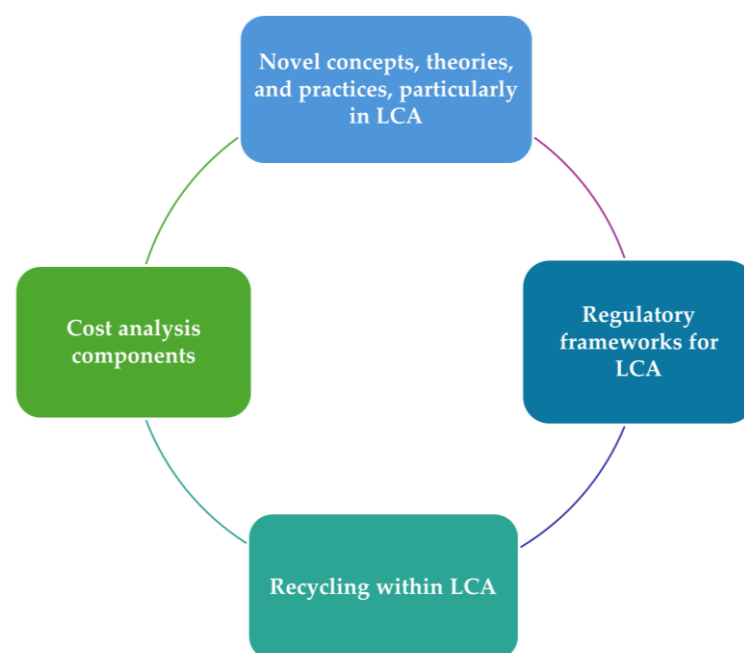


Figure 8. New knowledge in Course 7.

Course 8 introduced several novel concepts such as Open Strategy, which is the latest trend in the field of strategic management, specially designed for companies of all sizes that aim to innovate, as well as the Develop + Protect + Commercialize model, which is specifically tailored for the creation and development of deep tech startups [40]. Furthermore, experiential learning practices were introduced throughout the course to foster hands-on engagement, critical thinking, and real-world problem-solving skills [41]. By applying theoretical knowledge to practical scenarios, students were able to develop entrepreneurial

ideas, refine business models, and practice pitching their solutions, ensuring a deeper understanding of the concepts and preparing them for the complexities of the construction and innovation sectors [42]. The course integrated several emerging trends in the framework of the circular economy in construction, including the adoption of circular principles to reduce resource depletion and pollution, guided by the 10R Strategies Framework. This framework ranges from refusing unnecessary products to recycling and repurposing materials. There is a growing focus on “refusing” superfluous construction and “rethinking” building design to create multifunctional, adaptable spaces. Innovative technologies like 3D printing and bio-based materials are being used to reduce resource consumption and embodied carbon. Additionally, urban mining, which recovers valuable materials from buildings, is gaining momentum alongside the development of circular buildings designed for disassembly and reuse, promoting sustainability and reducing environmental impact. All these trends (Figure 9) were connected to the creation and development of innovative business models that are expected to shape the future of the construction industry [43].

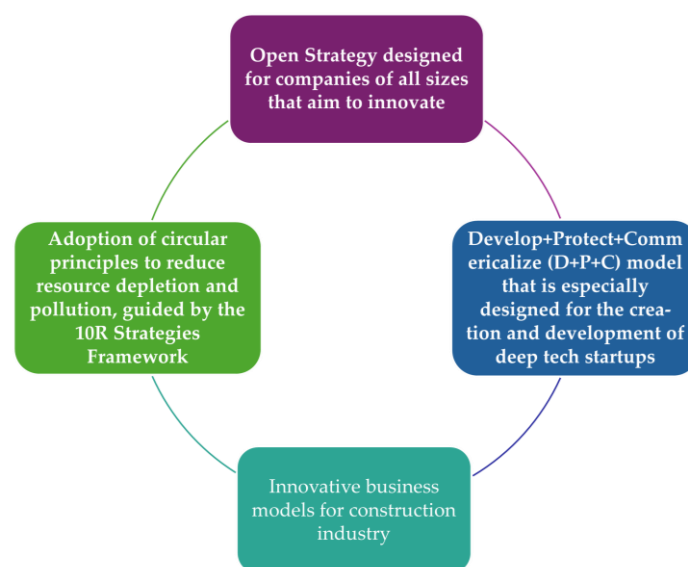


Figure 9. New knowledge in Course 8.

These emerging topics were identified through ongoing consultations with industry experts, research on global trends in construction, industry reports, and feedback from participants in related fields. The final curriculum was developed by the course leader and refined through discussions with the international team to ensure that it remained current and forward-thinking. Course 8 adopted an interdisciplinary approach by combining business model innovation with sustainability and circular economy principles in construction [44]. This fusion of innovation management and construction industry practices integrated into an experiential learning framework allowed students to address complex issues from multiple perspectives, making the content more comprehensive and applicable across disciplines [41]. The integration of multiple disciplines, such as innovation management, construction, intellectual property, and sustainability, greatly enhanced the comprehensiveness of the course. Students not only learned about construction-related issues but also how to create and adapt business models in response to environmental challenges, fostering a broader understanding of how these areas intersect in the modern marketplace.

2.2. Incorporation of Practical Applications

In all Courses, it was attempted to bring students in contact with real and practical applications. Involving students in developing real-life interdisciplinary projects that

encourage contact with companies and market representatives, combined with the implementation of digital tools and simulation software, which can also be used for distance learning, is a novel approach. The engagement of students in applying theoretical concepts to practical scenarios was facilitated through standard pedagogical methods. These methods, which included exercises, case studies, group work, workshops, and invited lectures, provided an interactive learning environment.

In Course 1, the legislative and normative framework for buildings was approached, and the differences between current buildings and buildings in 2050 were analyzed [11]. During the live streaming with professionals and the communication with the associate partners, practical issues were attempted to be presented to the students and trainees on the same topics. Students interacted with each other in real time using an online interactive board (Miro) and provided answers and inputs to the questions. Furthermore, close to the end of the course, a visit was scheduled in the region of Ribatejo, bringing the students to view different types of buildings and discuss their characteristics with teachers.

Course 2 integrated practical applications in all the topics through contact and discussion with industry and market experts who participated as educators. It also integrated cases from different countries, highlighting the international nature of the issues faced in the building sectors and showing that solutions can equally have an international effect and acceptance. Case studies were presented on thermal performance analysis of traditional and innovative materials and systems, including façades. Energy simulations were conducted with commercial software to better understand energy consumption in buildings and the differences between residential and non-residential buildings. Residential and non-residential buildings were simulated in six different locations with different weather conditions. Reference solutions for each country/region were used for the thermal envelope. The different types of consumption were calculated for each building and each location, and the differences were analyzed. Cases were also shown that exemplify future trends in heating, cooling, and DHW systems. Practical applications and examples of the use of Renewable Energy Sources (RES) to cover building needs were analyzed. A full example of using a photovoltaic (PV) system in a single-family house was analyzed. Energy demand was determined for a building not equipped with a photovoltaic installation, and then variants of PV installations with different parameters were selected. Their impact on the primary energy demand of the single-family house and the energy efficiency of this building were examined. It also demonstrated the use of biomass agglomerates as a sustainable alternative to fossil fuels, contributing to energy security and environmental sustainability. At the same time, recommendations were made for biomass combustion in domestic boilers.

Furthermore, practical examples were discussed, such as using thermal energy storage (TES) solutions using paraffin and hydrated salts for short-term storage solutions and a system based on chemical looping energy storage (CLC) for a long-term storage solution. It was also demonstrated with examples of how to increase building energy efficiency and indoor thermal comfort with passive solutions. Different techniques can be used depending on building type, structural characteristics, and climate conditions. The existing housing stock, especially in the Mediterranean area but also in Northern Europe, presents heavy structures with a high mass and high thermal capacity for which effective solutions can be evaluated by making interventions both on the opaque envelope and on the windowed components, according to the annual climate variations. Solutions range from the use of external insulation (ETICS systems) to facade addition systems (dynamic sunspaces), green roofs, and façades or to complete transformation of the massive facade with a curtain wall, also with the possibility of addition of active systems for the exploitation of energy from renewable sources, to reach nearly Zero Energy Building (nZEB) and PEB. Finally, practical

examples were provided for the use of Building Management Systems (BMS), Internet of Things (IoT) technology, and the integration of electric vehicles and charging infrastructure within the built environment and grids.

In Course 3, various activities were conducted, including interactive discussions on practical applications such as the urban water cycle and circular water principles, seminars on decentralized water systems with an emphasis on design and cost analysis, self-paced quizzes to reinforce learning, and group assignments to devise water management solutions tailored to specific building types. One assignment involved the preliminary sizing of a rainwater harvesting tank for non-potable uses. Participants applied this exercise to an unfamiliar residential dwelling, analyzing the technical and economic feasibility of implementing such a system. This practical task allowed participants to explore the real-world applicability of harvesting rainwater while evaluating its cost-effectiveness and sustainability. Additional activities encouraged participants to rethink urban water systems by integrating circular economy and resilience principles. These efforts emphasized water efficiency as a critical component of sustainable building management. Moreover, participants explored innovative approaches to urban stormwater management by adopting nature-based solutions (NBS), including green roofs, permeable pavements, and infiltration technologies, fostering a holistic perspective on sustainable water infrastructure.

In Course 4, the first part focused on delivering a shared knowledge base about the following concepts: the relationship between materials and environmental sustainability, deepening recent innovation in ceramic materials, composite materials, and materials for paving and streets; the choice of building envelope materials and the use of passive interventions (e.g., solar chimneys, reflective insulation) for energy saving; the interconnection between construction materials and the health of inhabitants in buildings; the structural concerns in sustainable construction. The second part was application-oriented as it aimed to develop a design project proposal based on local, sustainable circular materials, techniques, and innovative solutions, using technical datasheets and other specific databases provided during the classes. In that step, the participants worked in a team geographically mixed and then presented and discussed their proposals with teachers and the other trainees. Two practical activities were developed in a group of participants. (i) The first one dealt with the definition of the footprint ranking of construction and structural materials in sustainable construction under the coordination of partner IPS [11]. (ii) The second one, coordinated by UNIBO [11], was meant as a final challenge between groups of trainees focused on the development of a design project proposal for a technical solution (e.g., building component, stratigraphy for pavements and infrastructures, building envelope solutions) focusing on the corresponding local sustainable and circular materials and the innovative techniques and solutions, using technical datasheets and other specific databases provided during the classes. The projects must be referred to specific, realistic geographic and cultural contexts to develop a real-life project and analyze its technical feasibility in terms of construction and maintenance during the service life. The final design concepts were delivered in the form of a short video supported by graphical content. Presentations included the following contents: description of the geographic area and climatic zone and of the designed technical solution and its implementation; drawings and graphical representations and construction details; list of materials used and their characteristics; SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis; assessment of performances and of Embodied Carbon, based on the sources provided; feasibility analysis.

An overview of the main practical applications adopted in courses 1–4 is pointed out in Figure 10.

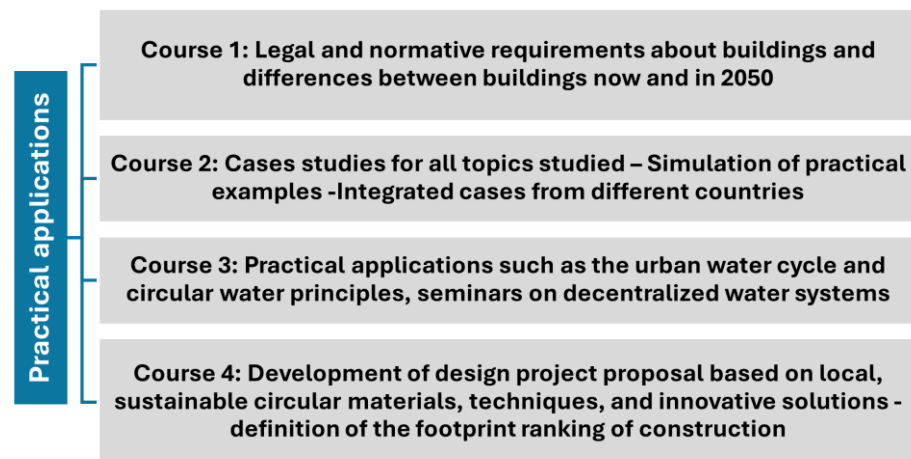


Figure 10. Practical applications in Courses 1–4.

In Course 5, the first part focused on providing shared knowledge on the following topics: Building Management Systems in buildings and data collection processes; data-driven fault detection and diagnostics in buildings; construction and control of hybrid heating systems containing heat pumps; structural health monitoring in buildings; survey methodology for historical or urban context.

The primary aims were the identification of digitalization tools and their applications in buildings to maximize the occupant's comfort with the lowest costs and optimize both the demand and the generation sides. Emphasis was put on practical applications such as measuring, extracting, storing, and processing data from buildings, and eventually, on how to make data-driven decisions. Obstacles and limitations related to building measurement and monitoring processes were also discussed, focusing on occupancy behavior, energy and economic savings quantification, and the implications of using advanced technologies. The course also covered the topic of Structural Health Monitoring (SHM) in buildings, highlighting its importance and main objectives and describing its workflow and components. A case study was presented, and new ideas and future applications of SHM were proposed as well. Furthermore, the course dealt with architectural and urban heritage knowledge and management, point clouds, and building information models. Real case studies were presented, showing how to perform a digital survey and underlining the importance of developing BIM models for existing constructions.

In Course 6, the first part was focused on key principles of sustainability and circularity in terms of construction systems and processes, strategies for deeply renovating the building heritage through energy refurbishment of facade (also including implementation of photovoltaic solutions, volumetric additions, and urban infill); urban regeneration strategies based on demolition and reconstruction of obsolete and inefficient buildings; healthy buildings and sustainable construction solutions; potentials of prefabrication techniques in terms of circularity. The second part was application-oriented as it aimed to analyze the requirements that sustainable, healthy, and regenerative buildings should meet and the ways to achieve them, with reference to the local construction techniques of the different EU contexts. In this step, the participants worked in a geographically mixed team and then presented and discussed their proposal of the requirements checklist with teachers and the other trainees. The lectures presented emphasized the way in which companies, industries, and other institutions designed relevant buildings in terms of health (wellness) and sustainability, considering environmental, social, economic, and technical issues. Two practical activities for participants divided into groups were developed: (i) The first one dealt with the simulation of seismic behavior, the assessment of occupant health and comfort, and the definition of end-of-life and regeneration proposals for selected construc-

tion and structural materials, with reference to the work developed in Course 4, again under the coordination of IPS. (ii) The second practical activity was meant as a final challenge between groups of trainees focused on the development of a shared checklist summarizing all the requirements that sustainable, healthy, and regenerative buildings should meet, considering the following aspects: technical, socio-cultural, regulatory and governance, and financial. Once drafted, this checklist was used as a guideline for developing a design concept for a sustainable and circular building system for new buildings or renovation of existing buildings. The project must be conceived with reference to the corresponding local techniques of the group members' countries of origin, using sources provided during the classes, including examples of real demonstration cases (e.g., the "Circle House Denmark's first circular housing" project [45]). This activity has been conceived as the final moment of knowledge sharing and synthesis of topics envisaged during the course. Since the practical activity for Course 6 was conceived as a continuation of the project developed during Course 4, again, the reference to specific real contexts was crucial in order to develop a design project endowed with concreteness and then assess its requirements with reference to current regulations and specific performance targets to be achieved. The final design proposals were delivered as a short video supported by graphical content.

Course 7 effectively integrated real-world examples, case studies, and practical applications to reinforce learning. A notable exercise was the climate profile assessment of building technologies, conducted in accordance with CEN standards, using a partially pre-filled spreadsheet as a resource [37]. Furthermore, students completed three assignments that were directly linked to LCA topics, providing a practical context for theoretical knowledge. In addition, the cost analysis classes included a collaborative workshop aimed at enhancing experiential learning. The course content was meticulously selected to address global challenges and contexts, acknowledging the diverse backgrounds of transnational students. It aligned with the main objective of the BUILD2050 project, focusing on sustainable construction practices for the future. The importance of LCA across all construction fields worldwide was emphasized, serving as a central theme in the course. Efforts to localize and adapt the content to specific cultural or regional contexts were evident. Instructors tailored discussions to include examples from their own countries while also extending analyses to a broader pan-European and occasionally global perspective [40]. This approach facilitated a comprehensive understanding of the material within diverse cultural contexts.

Course 8 integrated practical applications through exercises, group work, and workshops. Students were tasked with developing their own business models, analyzing case studies of innovative models in the circular economy and construction and applying the Business Model Canvas to real-world scenarios. These hands-on tasks ensured that theoretical concepts were directly linked to practical applications. Moreover, a couple of interviews with entrepreneurs talking about their business models in the circular economies were presented to students. At the first stage of the project, a novel idea generation methodology was applied to help students develop and shape entrepreneurial ideas. Each participant wrote a problem that she/he encountered in their professional life, creating thus a list of problems. In turn, each participant was asked to develop new products/services based on the problems of others. The initial course presented the 10R-framework that aims to present the global challenges leading to sustainability in the construction industry [43]. Furthermore, the course content was designed to address global challenges related to the circular economy and innovation in construction, which is in line with the goals of the project. Topics such as sustainable business models, intellectual property strategies, and environmental regulations are relevant across various regions and industries, making the content accessible and impactful for students from diverse backgrounds. The course integrated cases from different countries, highlighting how circular economy principles and

innovative business models are applied locally. Furthermore, as each participant worked on her/his own entrepreneurial idea, the concepts of the course were localized by each participant individually.

An overview of the main practical applications adopted in courses 5–8 is pointed out in Figure 11.



Figure 11. Practical applications in Courses 5–8.

2.3. Industry Relevance

All courses aligned with industry standards and guidelines, and representatives from industry, companies, and the market enriched the contents with up-to-date information on current practices and future trends.

Course 1 introduced students to international standards such as ISO/IEC 17025 for laboratory competence and to European legal and normative requirements for the building sector. During interviews with Municipalities (Moita Municipality, Grândola Municipality, Guarda Municipality) and Associate partner ADENE—Agência para a Energia, a Portuguese Energy Agency, students had the opportunity to understand and discuss in detail with them the approach and challenges regarding the decarbonization of building stock until 2050.

In Course 2, the students learned about building standards and regulations related to energy, indoor air quality, and thermal comfort (ASHRAE, ISO, and EN standards). They also learned about the energy performance of buildings standards (EPB Standards) that the European Commission has established to support the implementation of the Energy Performance of Buildings Directive (EPBD) and to assess the overall energy performance of a building. Furthermore, the interviews with industry and market experts (Figure 12) were important as their insights aided students in following the standards and new trends in the building design and renovation industry, supported deep comprehension and knowledge of the different systems and technologies used to achieve energy efficiency in the building sector. Zero Energy Buildings S.A. company, as BUILD2050 Associate partner, spoke about Zero Energy Buildings (ZEB): standards, policies, and practices.

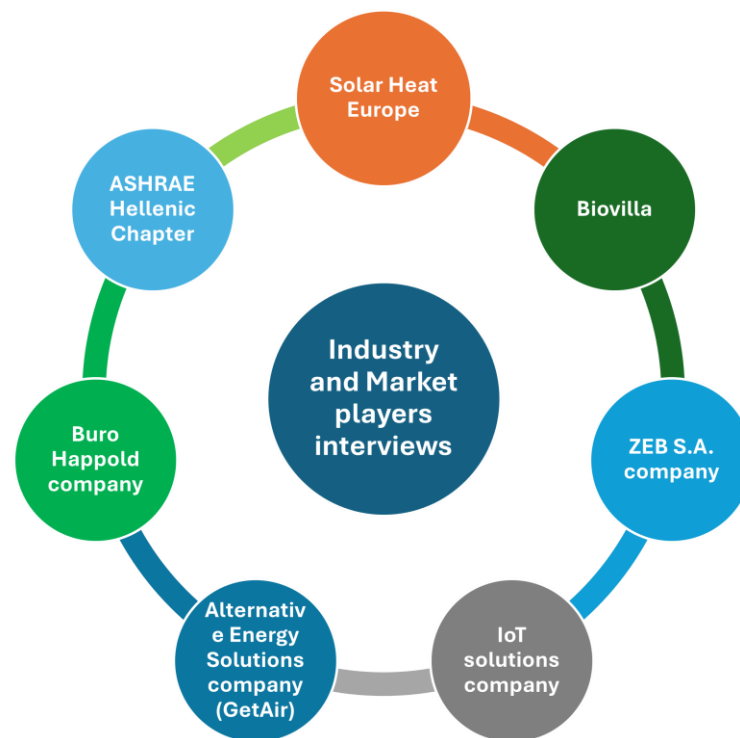


Figure 12. Industry and Market players that gave interviews in Course 2.

The students in that interview learned from a market player what ZEB buildings are and how they are different from conventional buildings. The most important standards for ZEB design were shown, as well as other advantages ZEBs offer to building owners and users beyond energy savings. ASHRAE Hellenic Chapter, as BUILD2050 Associate partner, explained the contributions of ASHRAE in terms of regulations and standards in the field of energy efficiency for buildings. Alternative Energy Solutions (Getair Hellas) company presented the most important standards for ventilation systems in buildings and the main differences between centralized and decentralized ventilation systems. It was also discussed whether decentralized ventilation units sufficiently replace centralized ventilation systems and the limitations and technological advancements. During an interview with Biovilla, a space of innovation, experimentation, and unity for sustainability in Portugal, energy-saving techniques and measures that are mainly applied in the design process to save energy to reduce their primary energy needs were discussed. With the interview with Solar Heat Europe, a European organization dedicated to supporting and promoting solar heat technology in Europe, students learned about current solar heating applications for the building sector and the challenges that solar thermal systems face now and for the next 30 years. The contribution of solar cooling systems in the building sector was discussed as a viable solution for the off-season use of solar thermal energy. A facade consultant from Buro Happold company presented light-building skin facades. IoT Solution company spoke about IoT systems in practice, the basic idea of IoT technology, communication standards, data collection, and data analysis. The importance of understanding how data flows and works with hardware and software components to create a final solution was emphasized.

In Course 3, key industry stakeholders contributed to the course, sharing insights on advanced technologies and practical implementations of circular water systems in Europe. These real-world examples enabled participants to bridge the gap between academic concepts and practical applications, ensuring relevance to the professional sector. The course emphasized industry collaboration, inviting experts to share cutting-edge innovations and real-world implementations of circular water systems. Key invited speakers included

COMVAL/KLARO company, which highlighted decentralized wastewater treatment technologies; a firm that addressed innovative rainwater harvesting solutions for urban and building contexts; and Simarsul company, which provided insights into centralized wastewater treatment and reuse strategies.

In Course 4, among the learning objectives was the comprehension of how innovative construction and local materials are used by companies, industries, and other institutions that work with construction materials. Indeed, several industrial partners have been involved as teachers for presenting real demo pilot cases and the related materials' applications according to the different standards: Kerakoll; the Italian Association Confindustria Ceramica [24]; Iterchimica; Europa Profil Alumium S.A. company and Isocor [27]. Their testimonies were crucial for highlighting the relevance of the different contexts' peculiarities and boundaries, which must be carefully assessed for a conscious and sustainable selection of materials.

Course 5 focused on identifying buildings as integrated systems and introducing control systems, building management systems, applications of building digitalization (fault detection, diagnostics, and structural health monitoring), and survey methodologies for historical and urban contexts. The only external industrial and market partner involved in the course was LSI Lastem, a company working in the field of environmental monitoring systems and instruments.

In Course 6, it was crucial to involve industrial partners and designers or project managers of professional firms from different EU countries in order to provide several practical examples of projects and interventions carried out for the renovation of existing or the construction of new buildings: ALIVA—IVAS Group [30], SEC—Scientific Engineering Constructions S.A., Vonovia [33], T&T [34], FRACTUS [35], PMMT Architects [26], JSJ Structural Engineering [36] and Earthship. Indeed, these target groups participated either in the role of trainers performing synchronous lectures, during which interaction with trainees took place, or in the role of testimonials, with contributions in the form of recorded interviews. Their contribution was crucial to the comprehensiveness of the course contents because, by presenting the work and projects in which they were involved, they enhanced the explication of the theoretical contents conveyed during the lectures by the academic partners. In particular, the testimony of the entities active in the field of EU research projects was considered a great resource because it is in this area that true innovative research in the construction field is developed.

Course 7 content demonstrated partial alignment with current industry standards and practices. Students learned about the EU and National regulatory framework for LCA for building design and European industry standards related to LCA, such as EN 15978 [37] and EN 15804 [38]. Crucial issues related to LCA, which are at the forefront of the construction industry, were systematically discussed, and practical examples were analyzed to provide contextual understanding. While the course was structured to impart substantial knowledge on LCA, particularly benefiting students entering the field without prior exposure, the initiative to enhance employability was indirect. It enhanced students' competitiveness in the labor market by imparting essential knowledge.

Finally, in Course 8, firms in all industries seek creativity and entrepreneurial mindset more and more. As the course fostered both those skills, it enhanced employability. Moreover, students were equipped with practical skills in business model development, value proposition creation, and the use of tools like Business Model Canvas [46]. However, there were no specific mechanisms to verify prior knowledge of these concepts upon enrolment. Students were asked to provide feedback after allowing the instructors to adjust and update.

3. Dissemination and Sustainability of the Trans-European Training Experience

Effective transnational training relies on an integrated approach combining strategic dissemination, efficient communication, and sustainability. Strategic dissemination identifies and engages key audiences, ensuring adoption across diverse cultural contexts. Communication strategies use multiple channels to make the training message clear and accessible internationally, while sustainability is achieved through lasting partnerships, continuous funding, and adapting to participants' feedback.

3.1. Dissemination Strategy

The dissemination strategy was developed using the following methodology (Figure 13). First, the strategy was designed, and the goals, the target groups/stakeholders and their special needs and characteristics were identified (DESIGN). Subsequently, the communication approach that will be used for each of them was determined (DO). Then, using adequate tools, the dissemination outcomes and results were collected and reviewed, and they were presented in reports (REVIEW). Finally, proposals are made with appropriate actions to make improvements (UPGRADE). To follow the steps of the dissemination strategy, as shown in Figure 14, three implementation phases were considered (Figure 14); each one of them has specific objectives, target groups, dissemination channels, content to be disseminated, and activities planned to disseminate results.

Dissemination and communication were organized internally and externally to cover the project and post-project periods. The internal part comprises the BUILD2050 partners [11] and the BUILD2050 network. The external part comprises organizations and any interested entities external to the BUILD2050 network.

The 1st implementation phase focused on the pilot training preparation during the first year of the project (2/2022–2/2023). The strategy and target groups/stakeholders that contributed to the development of the course's contents were defined. Associated partners were added, especially those who can contribute to preparing and evaluating content for each course. They are external to the consortium, including regional and national agencies, construction companies, municipalities, national research centers, and non-governmental organizations (NGOs). During this phase, the appropriate tools and channels were selected to support the collection of course content and the creation of the BUILD2050 network (DESIGN). On month 10 (12/2022), the courses were announced through the BUILD2050 partners' websites, professional organizations websites, newsletters, etc. Dissemination at this phase focused on the attraction of possible trainees, and it was made both internally and externally (DO), mainly through direct contact via email. The creation of the European network was supported by dissemination and events contributing to BUILD2050's sustainability. The 1st BUILD2050 Multiplier Event (ME1) was organized before the start of the pilot training (19–20 January 2023) and contributed to the attraction of trainees and associated partners both nationally and in the BUILD2050 partners countries. The pilot training was conducted during the 2nd implementation phase (3/2023–3/2024). Dissemination goals during that phase focused on attracting more trainees and expanding the BUILD2050 network. The latter contributes to updating the course content and supporting the attraction of trainees and in training replication. The dissemination channels exploited the partners' network (e.g., companies, NGOs, municipalities) while participation in conferences (national, international) was encouraged. The final 3rd implementation phase covered the last year of BUILD2050 (04/2024 to 01/2025), and dissemination activities focused on BUILD2050 training sustainability. During that phase, the goals were to disseminate and communicate the project results. Specific tools were developed during that phase, such as the BUILD2050 platform [47], the BUILD2050 eBook [47] and the European

Guide on Advanced Training for BUILD2050 [47]. Publications in international conferences and scientific journals were also exploited as a tool for dissemination [47]. In that phase, the 2nd Multiplier Event and the Final Conference were organized, where project results were presented, and fruitful brainstorming took place between the partners and events attendants, assuring promising ground for training sustainability.



Figure 13. BUILD2050 dissemination strategy.

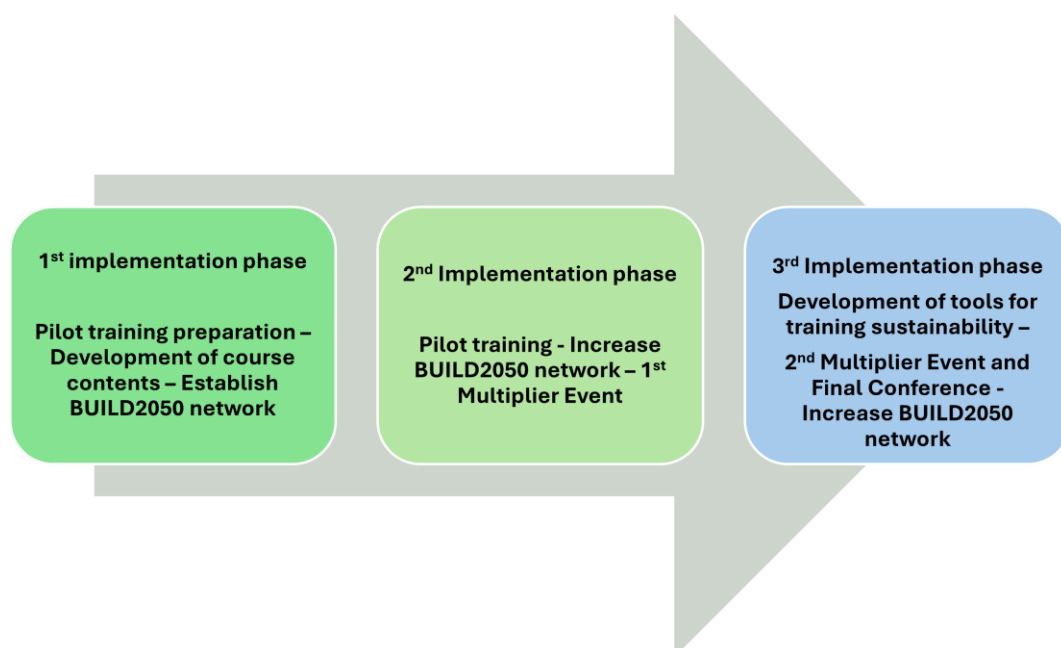


Figure 14. BUILD2050 implementation phases.

3.2. Dissemination and Communication Channels

A mix of tools was used to disseminate and communicate BUILD2050 results during each implementation phase. Promotional material was developed, such as brochures, leaflets, and videos. The website of the project [48] and online presentations on the partners' and professional institutions' websites supported effective dissemination of pilot training and all events that were organized. Furthermore, interviews in mass media, partners' social networks, personal communications, and emails were exploited.

It should be mentioned that one critical channel for the dissemination of the pilot training was the dissemination package that was developed consisting of the following documents and materials: (1) The call of the Pilot Training as a pdf document. (2) The call of the Pilot Training is a text document that each partner can edit and customize according to their needs. (3) A booklet with specific factsheets for each course, including accurate information, such as the program, objectives and learning activities, the calendar, the number of credits, and practical/logistics information, and (4) Templates for dissemination within emails, newsletters, and social media. Also, in that case, each partner could use and customize them accordingly. This was a very effective channel for the dissemination of the pilot training as it assisted partners in working in the same way.

Overall, the most effective dissemination channels were organized or/and developed during the project as explained in the following (Figure 15):

- **Multiplier Events (MEs):** The 1st Multiplier Event occurred just before the pilot training started (19–20 January 2023). It supported the efforts to attract trainees to the courses and supported connections with associated partners at national and European levels. The 2nd Multiplier Event took place after the end of the pilot training (25–26 June 2024) at the 3rd implementation phase, with the aim of promoting the results of the project's 2nd phase. The 3rd Multiplier Event (Final Conference) took place in the last month of the project (21–22 January 2025). It was the closing event, where all BUILD2050 results were presented. Multiplier Events targeted both national participants (students, teachers, associated partners, policymakers, etc.) and foreign participants (teachers, associated partners, etc.). All partners disseminated MEs using their own channels.
- **BUILD2050 eBook:** It compiled content developed from co-creation by trainees and trainers of the BUILD2050 pilot training and selected works and assignments developed by trainees during pilot training. Target groups include new graduates who could use it to expand their knowledge and skills, professionals who will gain new knowledge to be better prepared for the new challenges in the building sector, etc.
- **European Guide for Advanced Training:** It compiles the developed BUILD2050 methodology and content supporting the training replication by other higher educational institutions.
- **BUILD2050 platform:** It serves as an efficient channel for dissemination when someone visits it. All the project results, including course content, eBook, European Guide on Advanced Training for BUILD2050, and communication (workshops, etc.) are available in open access.
- **Scientific Articles:** The developed articles are listed in the BUILD2050 platform [47]. The first two articles on the pedagogical approach implemented in BUILD2050 pilot training were developed after the first phase of the project [47]. After the second phase of the project, an article focused on the new methodologies applied in BUILD2050 training courses, the results achieved, and the experience gained was published [11]. The current work is the final article that complements the other papers as it focuses on the new knowledge developed for the training and the methodology used to disseminate and sustain BUILD2050 results. All articles support the replication of BUILD2050 during the post-project period.
- **European network:** The BUILD2050 network was established from the early beginning of the project through the cooperation of all partners to invite possible associate partners to join the consortium, while procedures for the network operation were carefully defined. Target groups comprise researchers and research centers, national agencies, municipalities, companies, professionals active in the building sector, and further new higher education institutions, etc. The network encourages connections and contacts between active stakeholders in the building sector, integrating different

knowledge areas. The number of members of the network increased until the end of the project, and it is expected to increase in the post-project period. Considering the special interest shown in BUILD2050 training during events, it will be a challenge to connect with the network of European municipalities that are decision-makers in the building sector. Furthermore, another challenge is to connect with building professional organizations networks at national and European levels. The development and growth of the network will be a tool of the project that will enhance the transferability of the training.

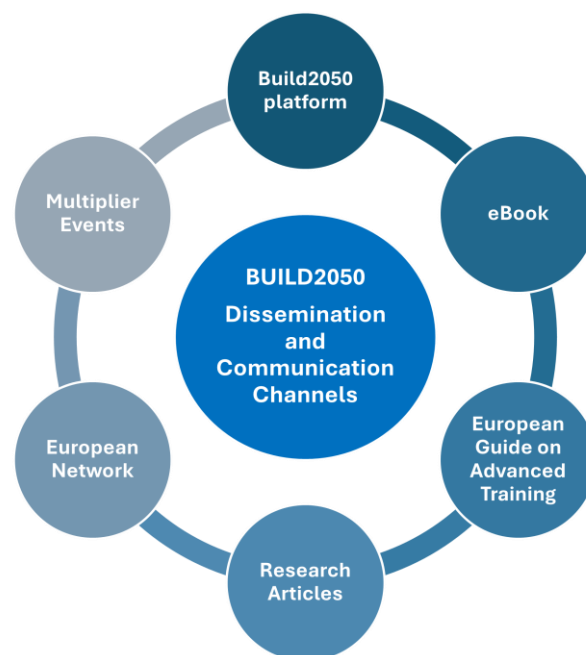


Figure 15. BUILD2050 dissemination and communication channels.

Finally, performance indicators were used for each channel and dissemination activity such as:

- o Multiplier events: number of events, number of participants, average size of the audience.
- o BUILD2050 eBook: number of downloads/views.
- o European Guide on Advanced Training for BUILD2050: number of downloads/views.
- o BUILD2050 Platform: activity indicators (number of visits, views, downloads, etc.).
- o Scientific articles: number of publications, type of journal, impact factor of journal, number of views/downloads (open access).
- o European BUILD2050 network: number of members.

3.3. Sustainability

From the beginning of the project, the goal was to implement a long-term strategy to develop BUILD2050 training in such a way—develop appropriate tools- that will support its replicability and sustainability in the post-project period. This is mainly based on consolidating the BUILD2050 network and using the BUILD2050 Platform, the European guide, the eBook, and scientific articles as contributions for training replication. A key activity in the sustainability strategy is the preparation of the second edition of the training. Furthermore, considering all the issues that the partners faced during the BUILD2050 training, and the experience gained, realizing best practices and points of improvement, some conclusions could be drawn to foster sustainability starting from the new edition of training:

- It is necessary to do more dissemination, and recruitment rounds for the training. This will reduce the time between the call opening and each course execution.
- Enhance the cooperation of all partners to increase the number of students from all partners' countries in all courses.
- Upgrade the pilot training, providing new insights and input by inviting skilled and qualified people as external partners to educate the project partners.
- In some cases, it is advised that the workload of trainees be reduced to become more attractive to the needs of working participants.
- As trainees have different backgrounds, it will be necessary to customize lectures and educational material in some cases.
- Use technical support for tools and platforms related to the IT tools [11] (Microsoft Teams and Moodle) by identifying a person responsible for those issues and having adequate preparation who is not a teacher/trainer in courses.

Technology plays a central role in the continuous improvement and delivery of the BUILD2050 training courses. Digital platforms such as Moodle and Microsoft Teams are used not only for course delivery and communication but also to collect feedback and monitor engagement, which informs future updates [11]. The integration of Building Information Modelling (BIM), Internet of Things (IoT) systems, energy simulation tools, and interactive collaboration platforms like Miro enhances the learning experience and ensures that content remains aligned with current industry practices [11]. Additionally, recorded expert interviews, online case studies, and the use of data-driven systems allow for agile updates to course materials in response to emerging trends, regulatory changes, and stakeholder needs.

4. Conclusions

This work presents the outcomes of the BUILD2050 project [11], highlighting the integration of new knowledge and practical applications within eight trans-European training courses focused on sustainable and climate-resilient building practices. It details new knowledge added in course content development industry collaboration, along with the dissemination and sustainability strategies adopted to ensure long-term impact. The project demonstrates how interdisciplinary, digitally supported education can bridge the gap between academic learning and real-world implementation to meet the EU's 2050 climate goals.

The BUILD2050 project has successfully addressed critical gaps in sustainable building education by incorporating new knowledge and fostering trans-European dissemination efforts. Through the development and implementation of eight comprehensive training courses, the project has significantly contributed to providing construction professionals, educators, and students the necessary skills to design and build in alignment with sustainability and circular economy principles. The project's key achievements include:

- **Integration of Sustainability in Education:** BUILD2050 has introduced innovative methodologies and knowledge that bridge academic learning with practical applications, supporting trainees with the necessary skills required to meet climate-neutrality goals by 2050.
- **Industry Collaboration and Real-World Application:** By engaging with industry experts, municipalities, and research institutions, the project has ensured that training content is aligned with market needs, enhancing the employability and competency of participants.
- **Trans-European Network for Knowledge Exchange:** Establishing a European network has facilitated the dissemination of best practices, fostering collaboration between institutions and professionals across different regions.

- **Long-Term Impact and Sustainability:** The project's outputs—including an eBook, a European training guide, and an open-access platform—provide valuable resources for ongoing learning and replication beyond the project's duration.

Moving forward, it is essential to sustain and expand the BUILD2050 network by engaging more stakeholders, updating course materials to reflect emerging trends, and fostering continuous learning within the construction industry. The courses are updated based on continuous feedback from trainees, instructors, and industry partners, ensuring alignment with evolving professional needs and learning outcomes. Additional criteria include the integration of emerging technologies, updates in EU building regulations, and shifts in sustainability and circular economy policies. When upgrading the courses, it is recommended to include additional topics such as construction and demolition waste (CDW) management, strategies for reuse and recycling, and the identification and mitigation of hazardous materials in existing buildings. These additions aim to enhance the curriculum's alignment with circular economy principles and address critical challenges in sustainable renovation practices.

According to the future strategy, the next course edition must consider the above aspects:

- the technology will play a significant role in course update
- optimizing course materials
- obtaining new funds for the implementation of further training courses
- reaching the largest possible group of potential listeners
- analysis of possibilities of the commercialization of training courses

Finally, the outcomes of the BUILD2050 project directly contribute to several recognized global and European sustainability frameworks. Specifically, the initiative supports SDG 4 (Quality Education) by promoting inclusive and future-oriented training, SDG 11 (Sustainable Cities and Communities) through its focus on sustainable built environments, and SDG 13 (Climate Action) by equipping professionals with skills for climate-resilient construction. Moreover, the project aligns with the EU Green Deal, the Renovation Wave Strategy, and the revised Energy Performance of Buildings Directive (EPBD) by fostering skills that are essential for achieving zero-emission building targets and a climate-neutral Europe by 2050.

Author Contributions: Conceptualization, S.L., M.K.K., N.C., A.C.B., R.S., C.M., J.A.-G. and A.D.L.; methodology, S.L., J.J., S.R., L.C., M.K.K. and M.G.V.; formal analysis, S.L., J.J. and S.R.; investigation, S.L., J.J. and S.R.; resources, S.L., N.C., L.C., M.K.K., A.D.L., J.K., M.G.V., T.B., J.A.-G., A.C.B., C.M., A.F., R.S., J.F. and P.T.; writing—original draft preparation, M.K.K., S.L., J.A.-G. and A.D.L.; writing—review and editing, M.K.K., J.A.-G., A.D.L., A.C.B., C.M., R.S., J.F. and P.T.; supervision, S.L., M.K.K., N.C., A.C.B., R.S., C.M., J.A.-G. and A.D.L.; project administration, S.L.; funding acquisition, S.L. All authors have read and agreed to the published version of the manuscript.

Funding: The work was funded by the Erasmus+ project Training for Sustainable and Healthy Building for 2050 (BUILD2050), Grant number 2021-1-PT01-KA220-HED-000032138.

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Greenhouse Gas Emissions from Energy Use in Buildings in Europe. 31 October 2024. Available online: <https://www.eea.europa.eu/en/analysis/indicators/greenhouse-gas-emissions-from-energy> (accessed on 13 January 2025).
2. Abdellatif, M.; Al-Shamma'a, A. Review of sustainability in buildings. *Sustain. Cities Soc.* **2015**, *14*, 171–177. [CrossRef]
3. Berardi, U. Sustainability Assessment in the Construction Sector: Rating Systems and Rated Buildings. *Sustain. Dev.* **2012**, *20*, 411–424. [CrossRef]

4. Zhao, H.; Frédéric Magoulès, F. A review on the prediction of building energy consumption. *Renew. Sustain. Energy Rev.* **2012**, *16*, 3586–3592. [CrossRef]
5. Maduta, C.; Melica, G.; D’Agostino, D.; Bertoldi, P. Towards a decarbonised building stock by 2050: The meaning the role of zero emission buildings (ZEBs) in Europe. *Energy Strategy Rev.* **2022**, *44*, 101009. [CrossRef]
6. Georgiou, C.; Maialetti, M.; Zorpas, A.A.; Salvati, L.; Vardopoulos, I. Policy and planning for “zero-net energy” real estate development in rural and exurban districts. In *Environmental Sustainability and Global Change*; Elsevier: Cambridge, MA, USA, 2025; pp. 291–303. [CrossRef]
7. Häkkinen, T.; Belloni, K. Barriers and drivers for sustainable building. *Build. Res. Inf.* **2011**, *39*, 239–255. [CrossRef]
8. Ahn, Y.H.; Pearce, A.R.; Wang, Y.; Wang, G. Drivers and barriers of sustainable design and construction: The perception of green building experience. *Int. J. Sustain. Build. Technol. Urban Dev.* **2013**, *4*, 35–45. [CrossRef]
9. European Commission. *The European Green Deal*; COM (2019) 640 Final; European Commission: Brussels, Belgium, 2019.
10. IPCC. Sections. In *Climate Change 2023: Synthesis Report*; Core Writing Team, Lee, H., Romero, J., Eds.; Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change; IPCC: Geneva, Switzerland, 2023; pp. 35–115. [CrossRef]
11. Koukou, M.K.; Lucas, S.; Justino, J.; Rafael, S.; Livieratos, A.D.; Carriço, N.; Konstantaras, J.; Vrachopoulos, M.G.; Benedetti, A.C.; Mazzoli, C.; et al. 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. *Buildings* **2025**, *15*, 67. [CrossRef]
12. Farias, T. Combinando a Economia Circular com a Descarbonização das Cidades: O Papel dos Edifícios. Master’s Thesis, Universidade Nova de Lisboa, Lisbon, Portugal, 2022. Available online: https://run.unl.pt/bitstream/10362/146991/1/Farias_2022.pdf (accessed on 15 January 2025).
13. Soares dos Reis, A. Avaliação de Soluções de Reabilitação de Edifícios no Âmbito da Sustentabilidade Ambiental. Master’s Thesis, Instituto Politécnico de Leiria, Leiria, Portugal, 2020. Available online: https://iconline.ipleiria.pt/bitstream/10400.8/7313/1/Projeto_MEENA_Alexandre_Soares_dos_Reis.pdf (accessed on 20 January 2025).
14. Horta, A.; Schmidt, L. *Pobreza Energética em Portugal. Policy Brief 2021*; OBSERVA, Instituto de Ciências Sociais: Lisboa, Portugal, 2021; Available online: <https://repositorio.ulisboa.pt/handle/10451/48206> (accessed on 16 January 2025).
15. Ganesh, G.A.; Sinha, S.L.; Verma, T.N.; Dewangan, S.K. Investigation of indoor environment quality and factors affecting human comfort: A critical review. *Build. Environ.* **2021**, *204*, 108146. [CrossRef]
16. Gabbar, H.A.; Ramadan, A. Integrated Renewable Energy Systems for Buildings: An Assessment of the Environmental and Socio-Economic Sustainability. *Sustainability* **2025**, *17*, 656. [CrossRef]
17. Coelho, L.; Koukou, M.K.; Dogkas, G.; Konstantaras, J.; Vrachopoulos, M.G.; Rebola, A.; Benou, A.; Chorapanitis, J.; Karytsas, C.; Sourkounis, C.; et al. Latent Thermal Energy Storage Application in a Residential Building at a Mediterranean Climate. *Energies* **2022**, *15*, 1008. [CrossRef]
18. Available online: <http://www.scores-project.eu/> (accessed on 18 January 2025).
19. Keller, J. Why are decentralised urban water solutions still rare given all the claimed benefits, and how could that be changed? *Water Res. X* **2023**, *19*, 100180. [CrossRef] [PubMed]
20. Exall, K.; Marsalek, J.; Schaefer, K. A Review of Water Reuse and Recycling, with Reference to Canadian Practice and Potential: 1. Incentives and Implementation. *Water Qual. Res. J.* **2004**, *39*, 1–12. [CrossRef]
21. Han, H.; Choi, C.; Kim, J.; Morrison, R.R.; Jung, J.; Kim, H.S. Multiple-Depth Soil Moisture Estimates Using Artificial Neural Network and Long Short-Term Memory Models. *Water* **2021**, *13*, 2584. [CrossRef]
22. Mo, L.; Wang, Q.; Bi, E. Effects of endogenous and exogenous dissolved organic matter on sorption behaviors of bisphenol A onto soils. *J. Environ. Manag.* **2021**, *287*, 112312. [CrossRef] [PubMed]
23. Rodonò, G.; Sapienza, V.; Recca, G.; Carbone, D.C. A Novel Composite Material for Foldable Building Envelopes. *Sustainability* **2019**, *11*, 4684. [CrossRef]
24. “Confindustria Ceramica” Italian Association. Available online: <https://confindustriaceramica.it/> (accessed on 14 January 2025).
25. “Biovilla” Portuguese Cooperative. Available online: <https://biovilla.org/biovilla/> (accessed on 14 January 2025).
26. “PMMT” Spanish Company. Available online: <https://www.pmmtarquitectura.es/> (accessed on 14 January 2025).
27. “ISOCOR” Portuguese Company. Available online: <https://isocor.pt/en/> (accessed on 14 January 2025).
28. Zanetti, E.; Kim, D.; Blum, D.; Scoccia, R.; Aprile, M. Performance comparison of quadratic, nonlinear, and mixed integer nonlinear MPC formulations and solvers on an air source heat pump hydronic floor heating system. *J. Build. Perform. Simul.* **2022**, *16*, 144–162. [CrossRef]
29. Apollonio, F.I.; Fantini, F.; Garagnani, S.; Gaiani, M. A Photogrammetry-Based Workflow for the Accurate 3D Construction and Visualization of Museums Assets. *Remote Sens.* **2021**, *13*, 486. [CrossRef]
30. “ALIVA” Italian Company, Part of “IVAS Group”. Available online: <https://www.aliva.it/en/index.asp> (accessed on 14 January 2025).

31. Mazzoli, C.; Corticelli, R.; Dragonetti, L.; Ferrante, A.; Van Oorschot, J.; Ritzen, M. Assessing and Developing Circular Deep Renovation Interventions towards Decarbonisation: The Italian Pilot Case of “Corte Palazzo” in Argelato. *Sustainability* **2022**, *14*, 13150. [CrossRef]
32. Mazzoli, C.; Iannantuono, M.; Giannakopoulos, V.; Fotopoulou, A.; Ferrante, A.; Garagnani, S. Building Information Modeling as an Effective Process for the Sustainable Re-Shaping of the Built Environment. *Sustainability* **2021**, *13*, 4658. [CrossRef]
33. “VONOVIA” German Company. Available online: <https://www.vonovia.com/en/about-us> (accessed on 14 January 2025).
34. “T&T” Portuguese Company. Available online: <https://www.tt-lda.pt/?lang=en> (accessed on 14 January 2025).
35. “Fractus” Portuguese Company. Available online: <http://fractus.pt/en/> (accessed on 14 January 2025).
36. “JSJ” Portuguese Company. Available online: <https://jsj.pt/home-box/> (accessed on 14 January 2025).
37. EN 15978-1:2021; Sustainability of Construction Works. Assessment of Environmental Performance of Buildings. Calculation Method. European Standard: Brussels, Belgium, 2021.
38. EN 15804:2012 +A2:2019; Standards Publication Sustainability of Construction Works—Environmental Product Declarations—Core Rules for the Product Category of Construction Products. European Standard: Brussels, Belgium, 2019.
39. Cadorel, X.; Crawford, R.H. Life cycle analysis of cross laminated timber in buildings: A review. In *Engaging Architectural Science, Proceedings of the Meeting the Challenges of Higher Density: 52nd International Conference of the Architectural Science Association 2018, Melbourne, VIC, Australia, 28 November–1 December 2018*; Rajagopalan, P., Andamon, M.M., Eds.; Architectural Science Association: Melbourne, VIC, Australia, 2018; pp. 107–114.
40. Livieratos, A.D.; Dimitrakopoulos, Y.; Tsinopoulos, C. Integrating lean startup tools in the technology transfer process: The ‘Develop+ Protect+ Commercialise’ model. *Int. J. Technol. Transf. Commer.* **2022**, *19*, 439–467. [CrossRef]
41. Kolb, D.A. *Experiential Learning: Experience as the Source of Learning and Development*; FT Press: Upper Saddle River, NJ, USA, 2014.
42. Gassmann, O.; Frankenberger, K.; Csik, M. The St. Gallen business model navigator. *Int. J. Prod. Dev.* **2013**, *18*, 249–273.
43. Reike, D.; Vermeulen, W.J.V.; Witjes, S. Conceptualization of Circular Economy 3.0: Synthesizing the 10R Hierarchy of Value Retention Options. In *Towards a Circular Economy*; Alvarez-Risco, A., Rosen, M.A., Del-Aguila-Arcentales, S., Eds.; CSR, Sustainability, Ethics & Governance; Springer: Cham, Switzerland, 2022. [CrossRef]
44. Takacs, F.; Stechow, R.; Frankenberger, K. Circular Ecosystems: Business Model Innovation for the Circular Economy. White Paper of the Institute of Management & Strategy, University of St. Gallen. Available online: <https://www.alexandria.unisg.ch/server/api/core/bitstreams/80845b25-a08c-4633-b118-3d2ae0682714/content> (accessed on 20 January 2025).
45. GXN and Responsible Assets, 2018. Circle House—Denmark’s First Circular Housing Project. Available online: <https://grafisk.3xn.dk/files/permanent/CircleHouseBookENG.pdf> (accessed on 5 February 2025).
46. Osterwalder, A.; Pigneur, Y.; Smith, A.; Etienne, F. *The Invincible Company: How to Constantly Reinvent Your Organization with Inspiration from the World’s Best Business Models*; John Wiley & Sons: Hoboken, NJ, USA, 2020; Volume 4.
47. Available online: <https://www.build2050.ips.pt> (accessed on 25 February 2025).
48. Available online: <https://build2050.weebly.com/> (accessed on 25 February 2025).

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.