sustainability

Article

Pedagogical Approaches for Sustainable Development in Building in Higher Education

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Abstract: Education for sustainable development (ESD) is one of the great challenges that university faculties have to face. Therefore, a multidisciplinary team from the faculty of Engineering of Gipuzkoa (EIG) at the University of the Basque Country (UPV/EHU) has developed pedagogical approaches to apply in construction degrees, namely Civil Engineering and Technical Architecture. Pedagogical tools, such as problem-based learning (PBL) or research-based learning (RBL), and environmental tools, such as the life cycle assessment (LCA) and computational thinking (CT), have been used; in doing so, they acquire a sustainable approach to work "soft-skills" competencies into sustainability. For example, research-based tools have helped to revalorize waste both outside and inside the university; they have contributed to more sustainable industrial processes, collaborative research projects, and participation in conferences and scientific publications. Based on academic results, the designed tools are appropriate for teaching in Technical Architecture and Civil Engineering degrees; however, to demonstrate their potential in terms of sustainable education, holistic rubrics based on in-depth quantitative educational research are required. Thus, to analyze the ability of the students to incorporate sustainability principles in their work, the multidisciplinary team presenting this paper plans to collaborate with psychologists and sociologists within the framework of the Bizia-Lab program of the UPV/EHU.

Keywords: ESD; higher education; teaching; engineering; construction; PBL; RBL; LCA; CT

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1. Introduction

It was in 1997 in Thessaloniki, at an International Conference organized by UNESCO, when the term "sustainability" for education started to be used [1]. Then, education for sustainable development (ESD) was endorsed by UNESCO's 37th General Conference in November 2013 and was launched at the UNESCO World Conference on ESD in November 2014 [2]. The common perception was that something more than a change in the teaching or curriculum was necessary: a change of the educational paradigm was raised. According to the three learning levels proposed by Sterling [3], a third learning level was required; that is, an epistematic or transformative learning. As university is a subsystem of society, oriented by its needs, values, and norms, a slow and laborious process was foreseen. However, a virus that appeared overnight forced us to totally revise and rethink many things. The university has had to reinterpret and transform reality creatively while facing social, economic, and environmental challenges. In this crisis, the real value of professions and jobs has become evident. They have been qualified by what they do for others, for the integrity of their ethics, for knowing how to put people at the center of their focus, and for their commitment beyond profit, security, and success. Professions have been valued for what they really are and how they further the common good, goals which are poles apart from success and individualistic careerism. In this context, there is an urgent need for the development and deepening of the transversal competencies proposed by ESD. It is time to change methods, forms, and instruments. It is, perhaps, the most propitious moment to look forward instead of returning to a stereotypical and routine, market-driven study method, with no connection to the community, humanity, or nature. ESD prepares learners to understand and respond to the changing world, thus driving sustainable development [4]. It produces learning outcomes that include core competencies in: foresighted thinking, an interdisciplinary work approach, a cosmopolitan perception, transcultural understanding and co-operation, participatory skills, planning and implementation, a capacity for empathy, compassion and solidarity, self-motivation and motivating others, and a distanced reflection on individual and cultural models [5]. We are facing a new educational paradigm, which suggests a change of epistemology from reductionism towards holism and from relativism to relationalism. This raises the need to use more collaborative and versatile teaching tools such as: brainstorming, peer assessment, problem-based learning, collaborative learning, online discussion forums, and games and systems simulations, for example [6–9].

The University of the Basque Country (UPV/EHU) developed the Campus Bizia Lab program between 2013 and 2016 as an initiative derived from the Project Erasmus University Educators for Sustainable Development. The aim of the initiative was to promote a collaborative process between academic staff, service and administrative staff, and students, creating a transdisciplinary community to respond to sustainability challenges within the university. It was an initiative driven by the Sustainability Directorate and the Educational Advisory Service, both belonging to the Vice-Chancellor's Office for Innovation, Social Commitment, and Social Action. Bachelor's degree dissertations and master's degree dissertations from several faculties (Engineering, Education, Science, Pharmacy, Economics, and Business) of the UPV/EHU were developed within the framework of the program. The challenges addressed in the dissertations were designed and based on a needs analysis in the campuses. Thus, they not only provided a return in terms of learning for the participants (students, faculty, and staff) but they also contributed to a more sustainable management of the university itself. Science, technology, engineering, and mathematics (STEM) are particularly affected by this transition towards ESD, as today's STEM students will be tomorrow's researchers, technologists, and leaders in industries worldwide [10]. Thus, within the framework of the program, some research projects have been developed by staff and students from the faculty of Engineering of Gipuzkoa (EIG) from the departments of Chemical and Environment Engineering, Thermal Engineering, Mechanical Engineering, and Architecture. The projects developed are aligned with the 17 Sustainable Development Goals (SDGs) of the United Nations Development Program with the main objective of integrating the results principally in the degree in Technical Architecture. EIG offers degrees, double degrees, international double degrees, and master's degrees, in which more than 1500 students are enrolled. In recent years, an approximate average of 50 new students are enrolled annually in the construction degrees Technical Architecture and Civil Engineering.

The aim of the degree in Technical Architecture is to study and apply different branches of applied technology to buildings. At a professional level, it is an activity that includes a series of different disciplines that cover the management of the execution process (both site and material execution management); advice and consultation within the field of buildings; structural projection and building installations; project management; urban management; construction, real estate, and development of the company management; analysis and calculation of costs and budgets; use management, comprehensive upkeep, and maintenance of buildings; as well as everything related to occupational health and safety, and quality control on construction sites. The degree in Technical Architecture has been designed so that students can acquire basic knowledge of building engineering in four years, as well as training that will enable them to access the labor market or postgraduate studies (master's degrees and PhDs) in engineering and other related disciplines. The study plan establishes that the type of teaching of the degree in Technical Architecture should be classroom-based and that students acquire 240 ECTS (European Credit Transfer System) credits distributed over 4 years at a rate of 60 credits per year. The degree is comprised of 14 modules: Installations; Fundamentals of Science; Basic Graphic Expression; Chemistry and Geology; Enterprise; Law; Specific Graphic Expression; Construction Techniques and Technologies; Process Management; Building Structures and Installations; Urban Management and Applied Economics; Technical Projects; and other areas and bachelor degree dissertations [11]. As can be seen, the academic degree reveals to be the cornerstone for achieving sustainability objectives from the professional perspective of the AEC sector. In addition, and given the great relevance for the students that connect with the company and professional world during the training stage, the EIG has implemented three university–company classrooms focused directly on sustainability. These classrooms include the Circular Economy Classroom, Sustainable Construction Classroom, and Energy Efficiency Classroom. All have the purpose of serving as tools to develop research projects, final degree projects, or informative conferences, among others, in such a way that it is possible to contribute added value to the training that students receive in the field of sustainability.

As analyzed in the previous paragraphs, it is of great relevance that today's society should acquire knowledge and skills in the field of sustainability so as to be able to redirect society towards a more prosperous future. Due to this, and given the relevance of the education sector in this field, the main aim pursued by this work is the design, development, and implementation of innovative educational proposals and alternatives to current teaching models, with a clear focus on concerns related to sustainability. Therefore, a multidisciplinary team from the EIG (UPV/EHU) has developed pedagogical tools that have been implemented in the construction degrees; in addition, all of them work "soft-skills" competencies into sustainability. In this initial phase, the proposed educational approaches have allowed students to be involved in multiple facets and activities related to sustainability, such as the research-based revalorization of waste both outside and inside the university, contributing to more sustainable industrial processes, collaborative research projects, and participation in conferences and scientific publications. Based on academic results, the designed tools are appropriate for teaching in Technical Architecture and Civil Engineering degrees; nevertheless, holistic rubrics are required to demonstrate their potential in terms of sustainable education. Therefore, the next phase in the process is the research and development of assessment tools to quantitatively determine the ability of the students to incorporate sustainability principles in their work that they acquired with the pedagogical approaches described. To carry this out, the multidisciplinary team presenting this paper plans to collaborate with psychologists and sociologists within the framework of the Bizia-Lab program of the UPV/EHU.

2. Materials and Methods

2.1. PBL: Problem-Based Learning

This teaching–learning method has been chosen to encourage and engage students in their learning process, and to obtain a more in-depth learning of the area regarding materials for construction.

Learning is an active process in which there must be engagement, thus motivation is required [12,13]. The fact that students come to learn freely and later undertake a job in a sector that they have presumably chosen is not sufficient motivation in many cases. Our young people receive endless external stimuli; their forms of leisure and learning mean that they can cope with challenges in many different ways, thus increasing their cognitive skills. Therefore, one must assume that they find the traditional teaching methods based on master classes and solving theoretical problems boring and not very motivating, resulting in passive students who, in some cases, eventually fail [14].

Research studies into university teaching indicate that the essential factor to foster academic success is students' engagement in their education and training [15]; understanding by engagement and the amount of physical and psychological energy that students invest in their academic experience are important to consider [16]. Engagement leads to the development of an activity and in the case of university, a mental activity, which must lead directly to in-depth learning, that is, to level IV which is relational and level V which is extended abstract, according to the SOLO taxonomy (Structure of the Observed Learning Outcome) proposed by Biggs and Collis [17].

Universities of international standing have developed teaching–learning methodologies in which students play a leading role in their education process, the so-called active teaching methodologies [18]. PBL, meaning problem-based learning, is one of the most highly developed methodologies in the university environment [19–21]. In PBL, students work independently to *explore* a problem proposed by the professor. With this methodology, the students themselves, during the work they carry out to solve the problem, encounter the curricular objectives. The professor acts as a mere facilitator of the task rather than a source of knowledge of the discipline. The basic difference, compared with traditional theoretical problems, is that the ultimate objective in PBL is not to solve the problem but to *discuss* how to solve the problem, which leads to the students' learning experience [22–24].

This methodology has been selected because previous experiences have shown that it provides students with greater motivation [12,25]. They develop thinking, learning, and working skills, and it also enables them to better retain information as well as integrate a working-knowledge model [19,26,27]. Moreover, with this pedagogical proposal, students acquire other transversal competencies, in addition to the typical ones of the degree:

- learning independently;
- applying new knowledge to solve different problems that are similar to those that will emerge in the different facets of their work;
- working as a team under supervision;
- identifying their objectives and in this case, learning objectives; and
- efficiently managing their time and benefiting, in this process, from their colleagues' collaboration.

Any PBL approach must have four basic ingredients:

1. the use of a problem as a starting point to acquire new knowledge;
2. the students manage their own learning;
3. group work; and
4. the professor acts as a facilitator [19].

The following basic actions must be carried out to plan the PBL:

1. Select the pedagogical objectives that, framed within the competencies established in the area, students should achieve with the activity [21].
2. Propose the situation/problem that students will have to work on, which must be (1) relevant for their professional practice, (2) complicated but not impossible, thus representing a challenge [20], and (3) extensive so that the students can ask questions and address the problem while taking the big picture into account.
3. Guide them through the rules of group work and activities conducive to solving the problem.
4. Perfectly establish the activity times.
5. Organize tutorials in which students can consult doubts, uncertainties, achievements, etc.

General pedagogical objectives of the PBL approach are that the students will be able to:

- plan tasks, assign responsibilities, and coordinate the teamwork [28];
- propose different problem-solving strategies and select the most adequate;

- analyze results and discuss them in a team, later transmitting the information orally and in writing using the specific terminology of the area and appropriate computer tools, including charts, PowerPoint, videos, simulations, etc.;
- define, experimentally determine by means of standardized tests, and calculate the physical and mechanical properties of the construction materials; and
- develop their own laboratory working skills and more specifically those conducive to identifying and analyzing the materials or their components.

2.1.1. The PBL Approach to Studying the Material Properties and Tests

The scenario of the PBL situation/problem to study the material properties and test them is located in the sculptures called the *Peine del Viento* beside the sea (Figure 1).

Figure 1. Images of the metal pieces that comprise the *Peine del Viento*.

This collection of sculptures, where natural rock and steel are combined, allows us to use it as an optimum scenario to study the physical and mechanical properties of construction materials. Conversely, in being located next to the sea, it suffers from the effects of the increase in wave size due to climatic change. This allows us to integrate the problem of climate change into the study of materials. Thus, *integrated problem-solving competency* (*IPS*) is worked on according to the competence matrix used to analyze the key competencies for sustainability from UNESCO [29], described and analyzed by Dlouhá et al. [30].

To facilitate the development of the teaching–learning process and to guide the students, the structuring problem is addressed via three sub-problems, as follows.

1. The physical properties of the materials: the properties of the rocks where the sculptures are anchored are analyzed, including the volumes, densities, porosities, humidity, etc.
2. The mechanical properties of the materials: the steel sculptures anchored to the rocks have been selected for study because, based on the mechanical properties of metals (especially steel), the most important mechanical tests on the construction materials can be described in terms of tensile, compressive, flexural, and impact strength.
3. The acoustic and thermal properties of the construction materials.

A situation/problem based on the initial scenario is posed again in each sub-problem, carrying out different activities to solve it based on cooperative learning techniques, including posters and puzzles [31].

2.1.2. Activities Conducive to Solving the Problem

Activity 0—drafting the group management rules: Innovation and development are no longer the result of an individual's genius but rather they arise from the knowledge and collaboration of a group of people. It has been fully demonstrated that group learning is much more than the sum of individual learning; hence, it is defined as one of the basic transversal competencies. As mentioned above, group work is a fundamental factor in the development of PBL [20]. However, for group work to be efficient, it must satisfy a series of requirements such as: the common objectives of the group must be clear, the atmosphere must be pleasant, with qualities including the active and reflexive participation of all members who must also be able to freely express their opinions, and listening in turn to the other members' opinions. Namely, mutual respect among participants is essential. For all of this to be fulfilled, it is important before starting to carry out the work to establish some group rules that all members must undertake to obey. The rules must be proposed by the actual group members and must be compiled in a written document, which must be available to all course participants. Thus, the first activity proposed in the development of PBL is to establish the management rules for the groups, which, throughout the entire PBL, will be comprised of three people. As this is not a PBL development activity, we have called this first activity Activity 0. To develop this activity, students freely form groups of three. The activity consists of them proposing and discussing what they consider should be fundamental rules to be obeyed when working in a group and what punishment must be imposed on any member who does not respect the rules. The faculty determines the time available to carry out this first part of the activity. The second part of the activity consists of setting out and discussing the rules proposed by each group in class. Finally, a person elected by the students will be responsible for drafting the rules, which are uploaded onto the Moodle platform.

The activities conducive to problem-solving are presented in schematic form in Table 1. They are separated into the three sub-problems (physical properties of the materials, mechanical properties of the materials, and acoustic and thermal properties), the methodology used, and the learning objectives to be achieved with the activity.

2.1.3. Assessment

All assessment processes must have three basic objectives [32]:

1. Evaluate students' learning results with respect to the objectives posed in the teaching plan, also bearing in mind that they are not just a set of knowledge but are disciplinary and professional competencies.
2. Compile information about students' learning processes so that it is possible to adapt the teaching to their needs and encourage them to make an effort to attain in-depth learning.
3. The assessment should be like a *quality control* of the teacher, that is, the assessment should be used to measure the degree of achievement of the course objectives, evaluating the efficiency of the teaching–learning method.

Furthermore, the learning-based assessment characteristics should: motivate students, detect their strengths and weaknesses, provide feedback about their progress, consolidate the work carried out, and develop students' self-assessment capacity. All of these factors are especially important when active methodologies are used. In the PBL case presented, the entire PBL design, including the tool methodologies, is at the students' disposal on the Moodle platform of the subject.

Table 1. Activities conducive to problem-solving, divided into the three sub-problems with the methodology used and the learning objectives.

Activity	Methodology	Learning Objectives
	Physical properties of the materials	
Classification of materials and properties	Photographic presentation	Identify materials and properties
Laboratory equipment	Bibliographic search, brainstorming in group, and discussion in classroom	Identify equipment to measure physical properties of the materials
Basic physical properties	Bibliographic search, poster, and discussion in classroom	Identify basic physical properties
Physical properties II	Bibliographic search, puzzle, and practical application for problem-solving	Identify derivative physical properties
Laboratory practice	Laboratory tests according to the regulation	Experimentally determine the basic physical properties of the materials
	Mechanical properties of the materials	
Mechanical properties	Bibliographic search, poster, discussion in classroom, and practical application for problem-solving	Identify basic mechanical properties of the materials
Laboratory practice	Tensile strength test of a steel according to the regulation (ISO 6892)	Experimentally determine the mechanical properties of a steel based on the stress-strain diagram
Laboratory practice	Brinell and Rockwell hardness test according to the regulation (UNE-EN 10003 and UNE-EN 10009)	Experimentally determine the hardness of different steels with different thermal treatments
Field practice	Visit to construction materials test laboratory	Concrete compressive strength test according to EHE (structural concrete)
	Acoustic and thermal properties	
Acoustic properties. Noise pollution thresholds	Reading a text and analysis, bibliographic search, brainstorming in group, discussion in classroom, and practical application for problem-solving	Notions of physics of sound and relationship with noise pollution, how it is measured and calculated, and graphic representation
Heat transfer mechanisms	Bibliographic search, puzzle, and discussion in classroom	Define the heat transfer mechanisms and identify them in buildings
Insulating materials	Search for technical datasheets on insulating materials and choice of materials to be applied in situation/problem (CTE–Technical Building Code, Guide on Insulating Materials and Energy Efficiency, EC Marking)	Identify insulating materials and choice according to requirements

2.2. NEST: Neighborhood Evaluation for Sustainable Territories

The methodology of the life cycle assessment (LCA) is an environmental analysis tool widely used in different sectors. The European Commission [33] and international bibliography recognizes LCA as being the best framework available to assess the potential environmental impacts of any activity, product, or service [34,35]. The first published studies of LCA took into consideration only energy use over the life cycle of a product or a process, whereas later studies included waste and emissions [36]; however, none of them went further than the quantification of materials and energy use. Thus, the Society of Environmental Toxicology and Chemistry, as well as the International Organization for Standardization, as part of its 14,000 standards series, with the 14,040 series focusing on establishing methodologies for LCA, developed a complete LCA methodology in the 1990s. The standard ISO 14040 was revised in 2006 and a new standard ISO 14044 was published [37]. This established that LCA was to be carried out in four distinct stages to generate a comprehensive overview of the total environmental effect: goal and scope definition; life cycle inventory (LCI); life cycle assessment (LCIA); and interpretation [38].

Further details on the current state-of-the-art LCA methodology can be found in the European Platform on Life Cycle Assessment [39].

The world urbanization rate increased statistically from 30% to more than 50% between 1950 and 2015, and it is estimated that it will reach 75% in 2050 [40]. It is thus considered to be of fundamental interest to mark lines of action that bet on urban solutions, which are resilient to climate change. Universities can be considered as "small cities" due to their large size, population, and the many complex activities that take place on the campuses. Furthermore, universities have the responsibility to lead by example [41,42]. Therefore, bachelor's degree dissertations on this topic have been carried out. The LCA tool used was NEST.

NEST was developed through a PhD thesis [43]. It is a PlugIn for Trimble SketchUp, one of the most widely used 3D modelers among urbanists and architects. The analysis is performed directly on the 3D masterplan of the neighborhood and performs the assessment of a set of indicators that was developed by associating a scientific approach. NEST presents a useful graphical and ergonomic interface to both analyze and confront theory with reality. NEST takes into account four major neighborhood components: buildings, land use (roads, parking, green spaces, etc.), infrastructure (public lighting), and the mobility of neighborhood users. The input data that NEST uses to perform the analysis can be entered manually (MA), manually by the NEST dropdown menu (MN), automatically by NEST (A), or the data can be imported from the Integrated Environmental Solutions (IES) software [44]. For the environmental and economic assessment of the building materials, refurbishment strategies, economic cost, embodied energy, and associated GHG emissions, NEST relies on an internal database of former analyses that estimate embodied environmental and production cost impacts of the different constructive systems and refurbishment strategies. This database was designed using national statistics, publicly available studies, data compiled from various studies [45], and data from international databases such as Ecoinvent for environmental aspects and Ecofys for economic aspects. To estimate the energy demand of buildings (heating, cooling, lighting, domestic hot water, and appliances), NEST requires the climate zone, the usage category of the building, and the energy label of the building as inputs. To convert the operational energy use values into economic and environmental impacts, conversion factors such as energy prices or GWP factors are automatically adapted depending on the location. It is also possible to manually insert this information and import energy simulation tool results (IES, for instance). To perform the analysis related to land use, NEST uses the type of surface (roads, parking, green spaces, etc.) and the area of the different surface types (m^2). The type of surface is defined manually during the modeling process using a "paint bucket" tool. The area of each surface type is automatically recognized in SketchUp and is defined through the NEST interface. Finally, NEST uses conversion factors to convert these amounts and types of land use into their respective environmental impacts [46].

Environmental Assessment of University Campuses

The concept of sustainability in the practices and missions of a university should not only address sustainability issues related to its management or provide better learning environments, but students themselves should also engage with this mission. Thus, within the framework of their bachelor's degree dissertations, by using NEST, the students carry out an environmental evaluation of the university campuses. First, they conduct an evaluation of the baseline impacts (the current scenario: the current buildings, lighting, infrastructure, and mobility characteristics of the campuses). Then, they propose several energy efficiency improvement strategies.

2.3. RBL: Research-Based Learning

Excessively theoretical teaching with little real application and insufficient preparation for research has been pointed out as an important deficiency in higher education. However, with the situation we have been in over recent decades in relation to climate change and even more during the pandemic that we are living through, the fundamental labor of science has become evident. More than ever in history, science has approached society. Nevertheless, in essence, initially by necessity and later, since Descartes, by imposition, science has had a purely reductionist character [47]. The scientific method is based on two complementary premises: analysis, which forces fragmentation to characterize the most elementary components, and synthesis, which allows the components to be integrated so as to be able to understand the whole. Thus, the need for the new holistic paradigm of sustainability forces science to open up and approach society with a holistic and inclusive character.

Different approaches relating teaching and research can be identified; in some of these approaches, the students assume a passive role, while in others, they assume a more active one. The most accepted approach in higher education is research-based learning (RBL). Any RBL approach must have five basic elements [48,49]:

1. recognize a research problem linked to the student curriculum, which allows them to deploy relevant scientific understanding;
2. require that the solution be capable of being found through research;
3. refine, which is needed to sustain the quality of the research work;
4. reward, which assesses the success of the activity; and
5. report, considering RBL is a kind of research and thus reporting on the research outcome is mandatory. This can be in the form of a written blog, article, poster, presentation in a seminar, or research publication, etc.

Regarding bachelor's degree dissertations at the EIG, students are offered the chance to participate as researchers in research projects, following a scientific methodology. These projects are also on sustainable development, specifically the circular economy. Research projects investigate the use of cement-based demolition waste as an aggregate for concrete and the use of municipal solid waste incineration fly ash to produce eco-friendly binders for building construction. The activities conducive to research are presented in schematic form in Table 2.

Table 2. Activities conducive to research with the methodology used and the learning objectives.

Activity	Methodology	Learning Objectives
Bibliographic review	Bibliographic search using databases of communication science such as ISI, EBSCO, or Scopus	Identify relevant information and key data
Lab experiments	Physical–chemical characterization of the materials used: cementitious waste aggregates from laboratory practices of construction materials of the construction grades, municipal solid waste incineration fly ash, and Portland cement Mechanical analysis, bending, and compression, according to the UNE-EN 196 standard	Identify equipment to measure physical–chemical properties of materials Experimentally determine physical–chemical and mechanical properties of binders for construction
Report	Writing the report to obtain the degree title following the outline of a scientific article: introduction (state-of-the-art), materials and methods, results, discussion, and conclusions Oral poster presentation and scientific paper-writing	Develop research experience, skills, and acquire relevant domain knowledge
Reward	Assessment of knowledge, skill, and attitude by faculty	Assesses the success of the activity, checking the learning outcomes and gaining both a deeper understanding and high order cognitive skills

2.4. Computational Thinking, Experiential Learning Theory

Computational thinking (CT) can be defined as the process of the mathematical and parametric modeling of the surrounding environment, including both natural and artificial systems and processes [50–52]. The goals of CT affect not only productivity but also the sustainability of the development of individuals and organizations [53,54]. Due to its proximity to mathematics, CT is an essential factor of STEM curricula and has received a strong impulse to improve the curricula linking with appealing new technologies. CT aims to merge computer programming and thinking skills, and it can be used in different scientific disciplines [55]. It has been proved that computational tools enhance the experiential approach and learning of scientific disciplines [56–58]. In this pedagogical approach, experiential learning theory (ELT) is the most appropriate framework for developing both CT skills and the mathematical processes of architecture and civil engineering [59].

The essence of ELT is the iteration over the cycle of concrete experience, observation, abstraction of concepts, and active design of experiences. In this experience, simulations in different computer tools become an indispensable tool [60]. For this purpose, different visual programming languages, such as Geogebra, ShinyApp, and Scratch, facilitate much of the process. In this setting, researchers work on the definition of visual tools that facilitate the teaching and learning of the calculus of fundamental architecture and civil engineering skills. Certainly, some authors led other authors to develop an activity in which students had to practice and learn both CT and isostatic beam-solving, giving rise to GeoGebra and similar open-source visual programming environments [61].

GeoGebra allows programs to be built by the graphical interactive composition and editing of blocks that control the actions of different actors. This approach to building algorithms makes programming fairly easy for beginners and has proven its efficiency in teaching mathematical concepts and abstract ideas at both the graduate and undergraduate level [62,63], as well as in enhancing exploratory and experiential learning theory [64]. Moreover, the researchers of this activity already have experience in this field, as they developed a workshop for teaching basic ideas about artificial intelligence in high schools and developed in Scratch, which is an open-source visual programming language. The objective fulfillment of this workshop has been validated through experiments [65].

CT is closely related to the fulfillment of ESD that pursues sustainability in education. Certainly, CT, combined with ELT, is aligned with the mobilization of resources and the implementation of innovative and context-appropriate solutions to provide education remotely, leveraging hi-tech, low-tech, and no-tech approaches. As for this objective, the authors used open-source software for better democratic access, making it scalable and modifiable by the community [66].

Moreover, CT enhances the sustainable approach to education as a lifelong learning process throughout the adult life of any person. Even though the workshop we describe in Section 2.4.1 is planned for undergraduates, the software we develop will remain open and accessible to anyone outside our university [67].

Finally, the acquisition of computational skills will provide students with some of the basics of the necessary skills they have to obtain in order to fight for their rights in an increasingly digital world. Technologies such as artificial intelligence and robotics are based on a mathematical and computational mental framework, and CT and ELT-teaching can enhance the awareness of these skills [68,69].

2.4.1. Exercise to Solve

Isostatic beam-solving is a classical and fundamental skill for building technicians and scientists. It involves solving leads to different internal effort diagrams, including axial effort or shear and bending moments. The knowledge of these diagrams permits building professionals to know what the maximum load of each type is and therefore to correctly size the beam section profile to support these loads.

The process of solving these exercises is based on the application of the three possible equilibrium static equations: the horizontal, vertical, and bending moment equilibriums along the beam, which represent the basic knowledge of every technical career. A generic example of the graphical results of this problem-solving technique can be seen in Figure 2.

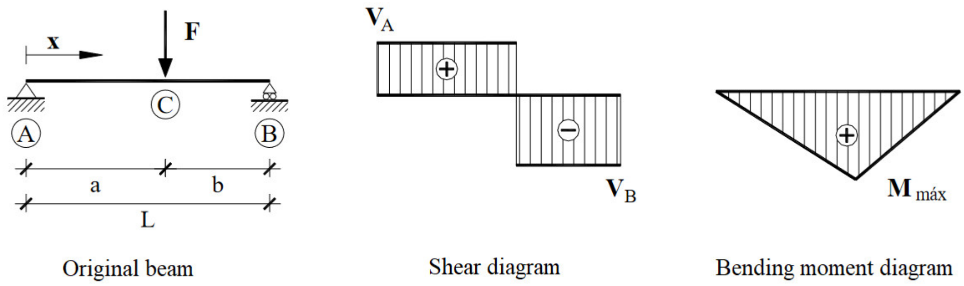


Figure 2. A generic example of the graphical results of the problem-solving technique.

As a general rule, an isostatic beam can be distinguished when the structural supports in the beam sum to less than a maximum of three static reactions. There is a wide variability in solving this kind of exercise, as there exists infinite possibilities to combine different supports, load values and distributions, and the distances between them. However, in all of these infinite combinations, the same isostatic equilibrium equations are used. For this purpose, the activity that researchers planned for a civil engineering student was the development of an automatic isostatic beam calculator with GeoGebra.

A bachelor's degree dissertation developed an automatic shear and bending moment diagram automatic drawer for the most habitual load types in these kinds of exercises. These load types are punctual, uniformly distributed, and triangular loads. The student did not have any specific computer skills and was not familiar with GeoGebra before. The resulting isostatic beam calculator can be found at this website: https://www.geogebra.org/m/dt8m7sws (accessed on 7 September 2021). As can be seen, anyone can introduce beams of different distances, combinatory loads, and distances between them in the software. After that, the program shows the axial, shear, and bending moment diagrams and highlights the maximum values. An example can be seen in Figure 3.

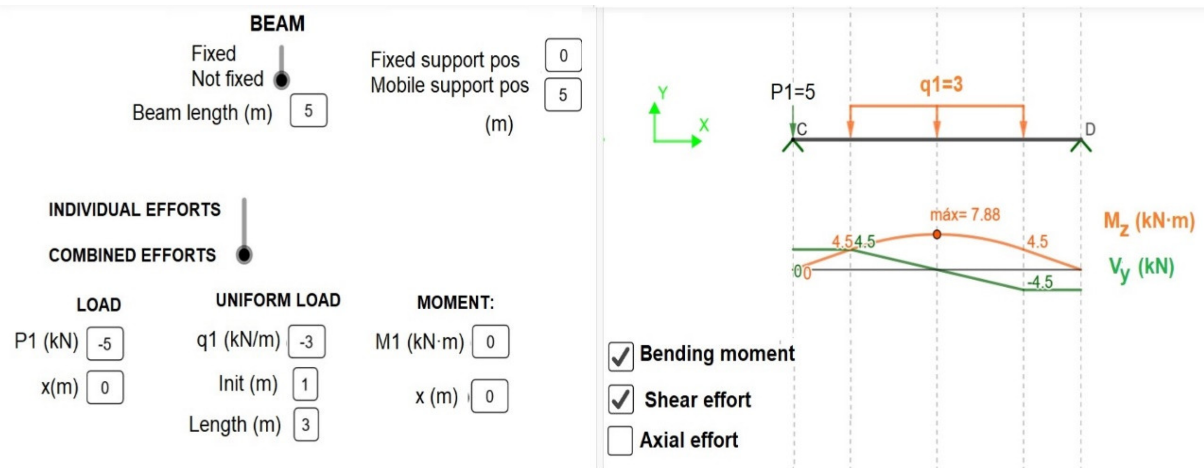


Figure 3. The axial, shear, and bending moment diagrams, highlighting the maximum value.

The project is scalable and different GeoGebra modules can be developed for different classical problem-solving exercises such as a hyperstaticity, beam vertical and angular deformation, or the calculation of normal tensions along the beam section. The objective of the project is to create a suite of different open-source software that enhances future students' exploratory learning of different static calculation exercises.

2.5. Remote Virtual Laboratory in the Area of Energy in Buildings

This decentralized action aims to apply sustainability criteria in the improvement of teaching resources in university education. Faced with the difficulties during the academic year of 2019/2020, with the unknown possibility for students to access laboratory equipment to carry out practical and experimental activities, a platform has been proposed that mitigates the lack of conventional laboratory practices. This problem becomes more pressing in the framework of the international ERASMUS student exchange agreements, in which the regulatory component of each of the countries in terms of mobility and travel permits may be different. Specifically, within the framework of these international agreements, students from the University of Paris Nanterre, from the thermal area of the LTIE, are received annually in our laboratories to carry out practical work and highly experimental end-of-degree projects in our facilities, in both the laboratory and the field, addressing the issue of energy efficiency in buildings [70,71]. Given the impossibility of displacement in the 2019–2020 academic year and in agreeing to provide an innovative solution, the practical application of new teaching methods in this group of students has been investigated.

From the EIG, in the thermal engineering laboratories, the team of professors have been working for several years on innovative methodologies in the educational field to solve the challenges generated over time. The latest research has been based on responding to the high number of students in practical classes and therefore the impossibility of all the students being able to use the equipment. Faced with this situation, actions were developed that consisted of promoting practical activities through computer programs in virtual learning environments (VLE) [72–74] with which students can interact and experiment with dynamic models, which are both representative of the subjects under study and which they have studied previously, achieving notable results, as noted in [75,76]. The applicability of these methods is adapted to the different teaching–learning modalities: lectures, classroom practices, and laboratory practices. It was found that within the laboratory practices, it is possible to adapt to the characteristics of the group of students in a more direct way by adapting to their learning needs and the nature of the subjects or practices.

Taking advantage of the aforementioned experiences, a proposal was made to adapt the environments to this exceptional situation. From the EIG, in the thermal engineering laboratories, a decentralized platform for remote access to the data generated by real equipment has been proposed, with the aim of maintaining the quality standards of the practical didactic proposal and addressing the difficulties raised. For this challenge, the design of a remote virtual lab (RVL) environment based on sustainability has been chosen. It has been used for the development of learning environments for practical activities, as well as for open universal access software and hardware [77,78], based on various technologies such as Arduino, Raspberry Pi, and IoT, and its integration with building modeling environments through Building Information Modeling (BIM).

The proposed work area includes practical applications for improving energy efficiency in buildings. In this area, the monitoring of environmental and energy variables in buildings [79–81] and their constructive solutions are active improvement tools for optimizing the use of resources and energy sustainability. In addition, it also provides application assets to buildings and smart cities, to the control of the health and wellbeing of the buildings' users, as well as to the evaluation of the indoor air quality (IAQ) of the living spaces. This fits with the SDGs, mainly with the following: #4 quality education, #7 affordable and clean energy, and #11 sustainable cities and communities. Once these needs have been detected, we take advantage of the monitoring infrastructure developed by the authors [76], with interactive elements that allow for the understanding of the theoretical contents and for access to the test elements by means of communication between the real physical world and the user through the sensors and IoT communication networks, all based on open-source platforms (OSP) following the objectives of universal access and sustainability.

However, it is necessary to connect this network architecture with the physical infrastructure and enable face-to-face access to the database equipment. The strict measures of home confinement that were experienced both in origin (Paris) and in destination (Donostia-San Sebastián) prevented all access to shops or supplies. Thus, to implement the transmission set, the virtualization of the operating systems and the physical components required at source were carried out. To solve this challenge, Virtual Box was used to simulate the Raspberry Pi OS, as depicted in Figure 4. This innovative solution allowed students to access all the functionalities through simulation and without requiring the necessary SBC hardware from their private homes. Thanks to this, the students were able to simulate the destination simultaneously and it was possible to carry out the practice in the expected terms of quality and innovation.

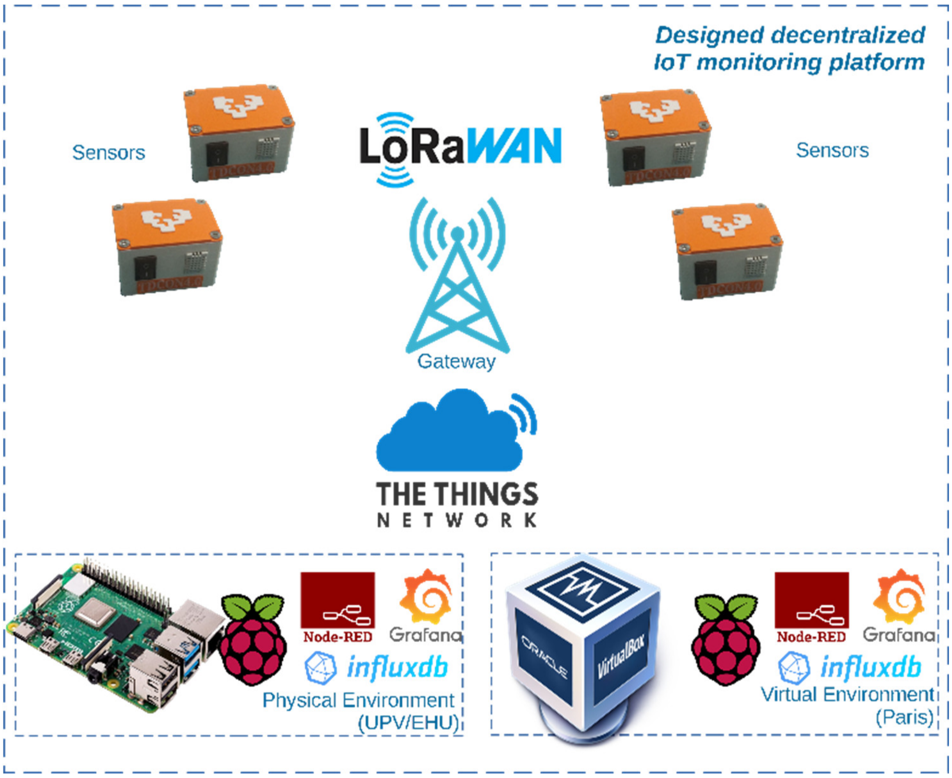


Figure 4. Graphical scheme of the implemented RVL methodology.

This is an example of a line of work that has demonstrated its high replicability in other areas, being a very interesting tool for combining other teaching methodologies such as PBL or RBL, in which students acquire a greater role in the active learning process in subjects related to sustainability. In order to monitor the progress of the tasks in real time, the teachers acted as facilitators, tutoring the students through the Blackboard Collaborative tool.

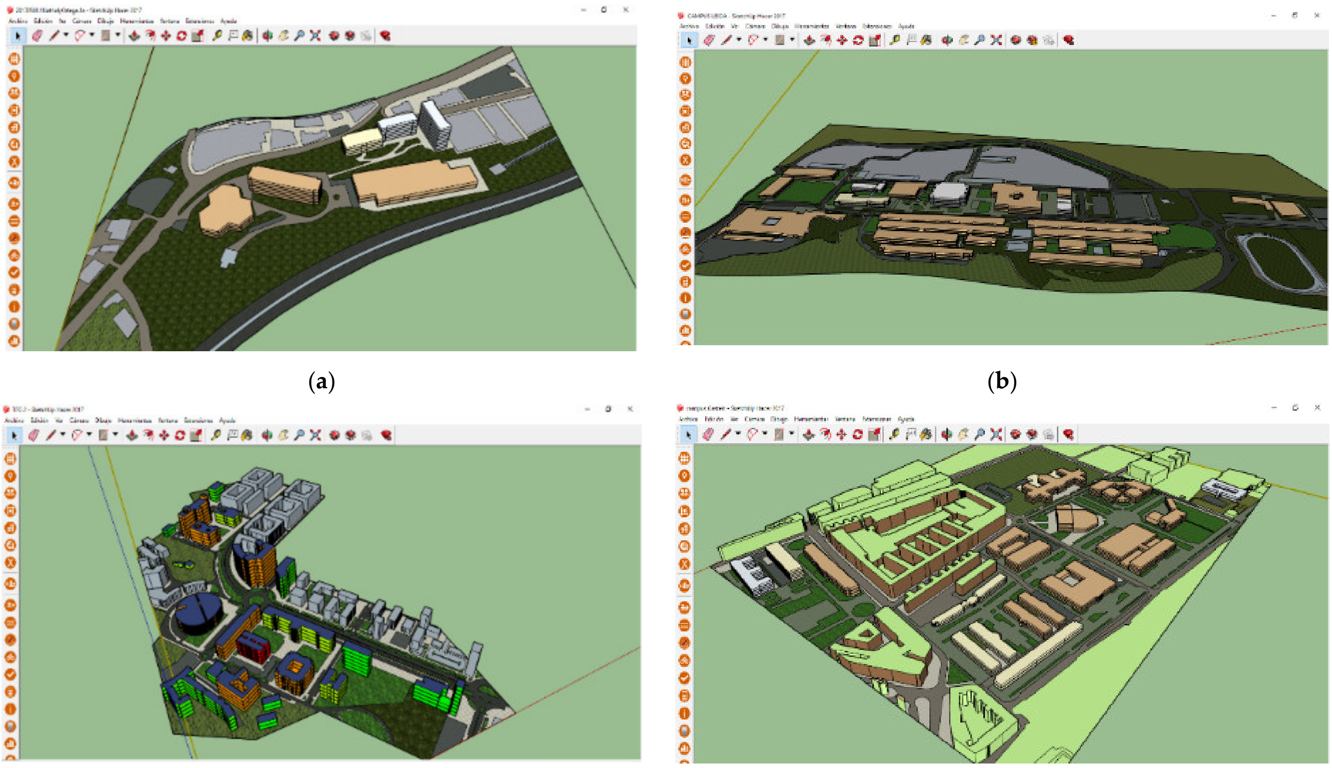
3. Discussion

3.1. PBL: Problem-Based Learning

The model of PBL was designed during the 2012–2013 academic year and was implemented in the classroom for the first time during the 2013–2014 academic year. After the implementation of the PBL, it was been observed that students receive better marks in the partial exams of physical and mechanical properties, which shows that it is a good pedagogical tool to acquire the competencies of the subject. Furthermore, greater involvement in the teaching/learning process, together with improvements in teamwork and collaboration, as well as in increased awareness of climate change, have also been observed.

3.2. NEST: Neighborhood Evaluation for Sustainable Territories

The results obtained with the NEST tool are of great interest both for the scientific community [46,82,83] and for the UPV/EHU in its initiative towards a sustainable university. When the four campuses of the UPV/EHU were analyzed, some critical issues were understood. On the one hand, the evaluation helped to identify the critical environmental impacts and therefore to define the key action areas. On the other hand, comparing different scenarios helped to show the different impacts that each type of university campus has. Thus, it could be seen that rehabilitation strategies are more effective in compact suburban university campuses, while they are more limited in the urban campuses. With respect to PE and total GWP, we saw that mobility especially penalizes the suburban campuses. It was concluded that tools such as NEST can help university designers to achieve an optimized design of university campuses in terms of their location, typology and distribution of buildings, and for the governing authorities to establish improvement policies. These results obtained in the development of the bachelor's degree dissertations were presented in two congresses: (1) the 8th European Congress on Energy Efficiency and Sustainability in Architecture and Urbanism, in addition to the 1st International Congress on Advanced Construction in Donostia-San Sebastián, 3–5 July 2017, and the (2) University and Sustainable Development: Learning experiences that compromise the future at the international conference RED-U 2017 in Bilbao, 13–14 November 2017. One of the students gave a 20-min oral presentation of their work (Figure 5 shows the graphic results). In addition, the students obtained marks of excellent in their final dissertations.



(**a**) (**b**) (**c**) (**d**)

Figure 5. Screenshots of the four campuses: (**a**) Eibar, (**b**) Leioa-Bilbao, (**c**) San Sebastián, and (**d**) Gasteiz, made with SketchUp by the students.

3.3. RBL: Research-Based Learning

The evaluation of RBL was carried out based on the results derived from its development, with important repercussions for the university, as follows.

1. Revalorization of waste generated in laboratory practices of engineering and construction degrees. As shown in Figure 6, aggregate for mortars is obtained from the cementitious residues of the laboratory practices, which were mixed with commercial sand in the appropriate proportion according to the results obtained experimentally. The test samples are used to study the mechanical behavior of cement.
2. Incorporation of ESD laboratory practices as a part of the curriculum.
3. Revalorization of waste outside the university, involving municipal solid waste incineration fly ash, which has been previously characterized [84], is used for the manufacturing of eco-binders.

4. Collaborative research projects and bachelor's degree dissertations with centers outside the university: Tecnalia, CSIC, etc.
5. Participation in conferences and scientific publications.

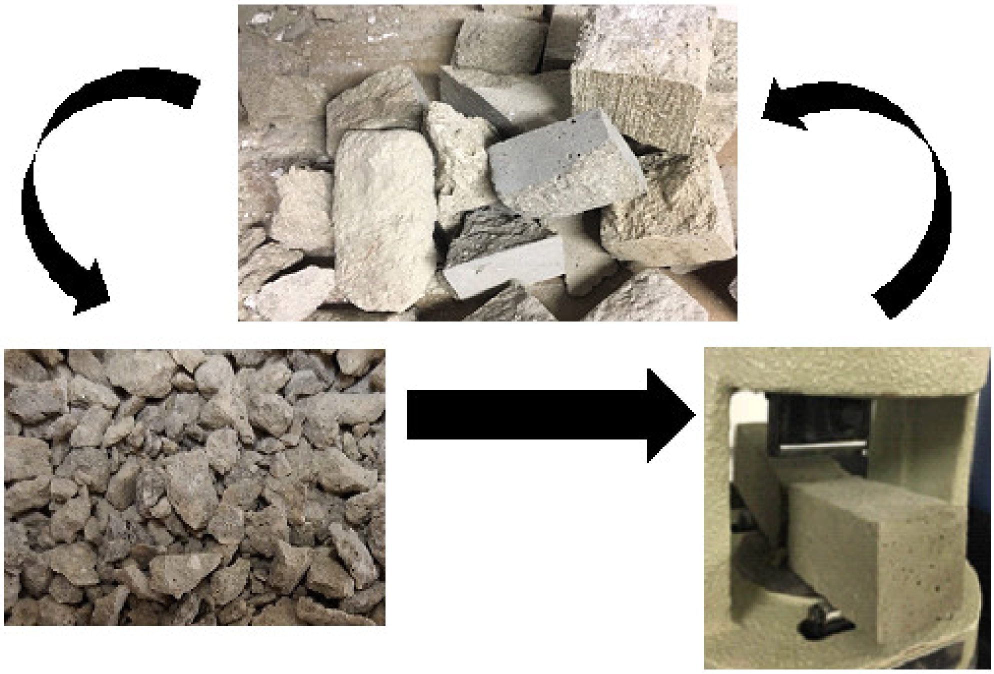


Figure 6. Circular economy in construction laboratories.

3.4. *Computational Thinking, Experiential Learning Theory*

The isostatic beam calculator has been implemented as a class tool for the following subjects: structure theory and structure technology. In the first, the basics of resistance material concepts are explained and applied to different beams, such as torsion, deformation, tension calculus, or buckling. In the second, the cross method for the calculus of continuous hyperstatic structures is explained. The calculator is used during class as a support material for students. They can check the numerical results they obtained by hand with the calculator and thus check their hypothesis. As an extra advantage, while studying for exams, students could create new beam situations by themselves and could check the results with a validated calculator.

The performance of both grades in architecture and civil engineering is quite similar and the use of the beam calculator tool was the same with all of them. Before the calculator, more than 25% of students failed the exam exercise related to diagram drawing; after the implementation and practice using it, this was reduced by almost a half. As no kind of extra change in teaching procedure existed in this aspect, it is quite clear that the effect of self-exploratory computational thinking helped the students to understand this calculus. In addition, this tool proved to be very valuable during the pandemic and online classes. Thus, we are thinking about possible expansions of the software. Furthermore, the students have already shown an interest in taking part in the development of these tools.

However, due to the special conditions of last year during online classes in the pandemic, the tool requires further research and practice in order to assure that the improvement of students' scores is due to the beam diagram calculator [85].

3.5. Remote Virtual Laboratory in the Area of Energy in Buildings

The results derived from the project developed under the RVL methodology are the workflow itself, as depicted in Figure 7, based on the conception and development of a virtual remote system able to collect, store, manage, and view data acquired by the monitoring sensors of the EIG (Donostia-San Sebastián) from the students' location (Paris).

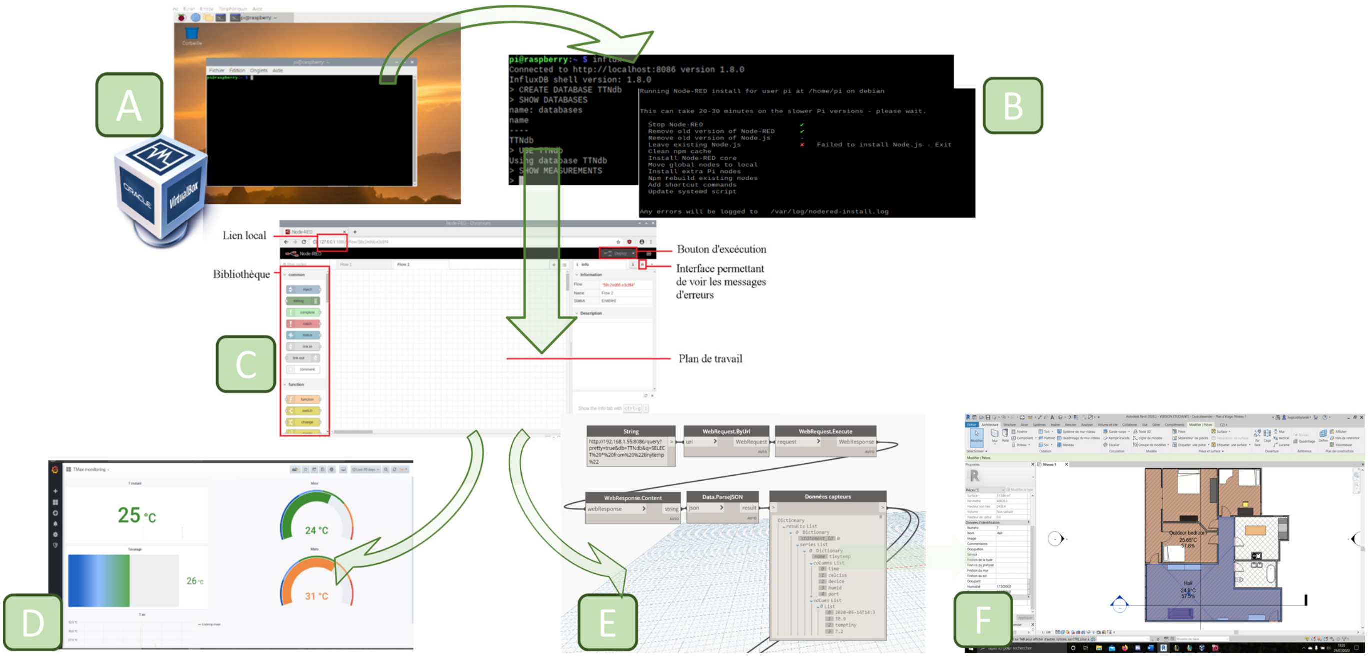


Figure 7. Workflow followed by the students under the RVL methodology during the project development. (**A**): Raspberry Pi OS simulated under VirtualBox, (**B**): Command-line interface of Raspberry Pi OS, (**C**): Node-RED environment, (**D**): designed dashboard in Grafana, (**E**): developed script in Dynamo, (**F**): Revit model.

To do this, the students first proceeded to install the Virtual Box machine in their computers with Windows OS, with which they could simulate the Raspberry Pi OS, as depicted in Figure 7A. The next step, as depicted in Figure 7B, consisted of performing the installation through the command-line interface (CLI) of the Node-RED, InfluxDB, and Grafana software stack. Through the Node-RED, as depicted in Figure 7C, the data was redirected from The Things Network (TTN) platform to the database generated in InfluxDB by using a node that acts as an MQTT client and collects the data received on the network server through port 8883 and the subscription of the desired topics.

The stored data was then used. First, different types of dashboard panels were designed through Grafana, as depicted in Figure 7D, given its high potential for creating intuitive data visualization panels. Additionally, given the great relevance of BIM software in the AEC sector and taking into account the high potential of IoT technology in fields related to asset management, the data collected by the sensors were integrated into the BIM model. To do this, a script was developed through the visual Dynamo programming interface, as depicted in Figure 7E, which made it possible to redirect the data collected in the database directly to the model developed in the Autodesk Revit software, as depicted in Figure 7F.

The work carried out by the students allowed for the development of a flow parallel to the one developed from the EIG, without requiring physical monitoring equipment due to the virtualization of the work environments and the collection of data through both TTN and Node-RED. It is worth mentioning that for the correct monitoring and guidance by the teachers of the work developed by the students, one of the key tools was the use of the Blackboard Collaborate web application. It should be noted that in order to address the adversities generated by the impossibility of conducting a face-to-face follow-up with the students, this tool revealed to be vital as it offered many very useful advantages that allowed for two-way communication between both parties. Among others, the following advantages offered by the platform should be highlighted:

- possibility of using the application without requiring the installation of any program since it is a web tool with access from a link;
- intuitive and easy-to-use graphical user interface (GUI);
- possibility of using the Blank Whiteboard tool to develop diagrams;
- share presenter screen/app;
- share files; and
- share recordings of the sessions to be consulted later.

4. Conclusions

ESD requires the use of different pedagogical approaches. In the present work, those developed for use in engineering and construction degrees have been set out. Some of them are widely used tools implemented in many universities, such as PBL and RBL; another based on a widely disseminated environmental tool, such as the LCA; and others that have been developed specifically for use in these degrees. All of them are characterized by the fact that, in one way or another, they work on competencies in relation to the SDGs, which were adopted by the United Nations in 2015 as a universal call to action to end poverty, protect the planet, and promote peace and prosperity for the whole planet. In Figure 8, the goals covered in the pedagogical approach proposed in the present work are highlighted.

Figure 8. SDG adopted through the proposed pedagogical approach for the ESD in EIG (UPV/EHU).

The proposed pedagogical approaches allow for the adoption of different SDGs, developing a comprehensive vision of the existing challenge in the field of sustainable development, based on the Brundtland Report [86], particularly in environmental and economic dimensions. Thus, the NEST and RVL educational proposals promote SDG-7 and 11. From different perspectives, the analysis of the energy and environmental impact of buildings and cities are carried out. In both approaches and in line with both energy strategies and policies applied in buildings, improving energy efficiency becomes an aspect of maximum relevance as a method to reduce environmental impacts. Through the use of modern simulation tools and monitoring technologies, it is proven that feasible alternatives for analysis towards new, more sustainable scenarios than the current ones are possible.

The approach presented through RBL is also committed to achieving the SDG-9 and 12 objectives, based on research related to the circular economy, through the revaluation and reuse of concrete waste generated in construction and fly ash from municipal solid waste incineration. Both cases are examples of research promoting sound management and waste recovery. Furthermore, this new approach would also make it possible to modernize the production infrastructure of the industrial sector through developing new innovative manufacturing processes based on environmentally sound models by means of using resources more efficiently.

Another one of the objectives worked on throughout the different proposals concerns SDG-17. International agreements on education, through the framework of the Erasmus + program, have made it possible to foster cooperation between the UPV/EHU and the Université Paris Nanterre. In addition, the agreements and work carried out in the field of research with other technology centers (Tecnalia and CSIC) presented in the RBL approach have allowed for the exchange of knowledge between the institutions, in addition to promoting the development and dissemination of environmentally sound technologies.

Therefore, it can be concluded that with the developed approaches, the student is trained to acquire knowledge in their branch of study, as deduced from the improvement in academic results. However, it must be taken into account that the 2019/20 and 2020/21 courses have been those of the pandemic and the lessons have had to adjust to the new situation; thus, as proposed by Engelhardt et al. [87], the improvement in the results may be due to a variety of reasons. Conversely, keeping in mind that this paper is not an empirical study but rather a detailed description of pedagogical approaches for sustainable development, in order to quantitatively determine the students' ability to incorporate sustainability principles into their work, an exhaustive analysis of the results through in-depth educational research approaches remains open for future phases. Thus, the EIG's multidisciplinary team working on the EDS plans to collaborate with psychologists and sociologists within the framework of the Bizia-Lab program [85], as well as with professionals in the field of educational research, offer a broader and more concrete vision of the determining aspects that most influence the educational phase of students from approaches related to sustainability.

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Abbreviations

EIG	Faculty of Engineering of Gipuzkoa
UPV/EHU	University of the Basque Country
PBL	problem-based learning
RBL	research-based learning
LCA	life cycle assessment
CT	computational thinking
ESD	education for sustainable development
STEM	science, technology, engineering, and mathematics
SDG	Sustainable Development Goal
IPS	integrated problem-solving competency
ECTS	European Credit Transfer System
SOLO	structure of the observed learning outcome
CTE	technical building code
NEST	neighborhood evaluation for sustainable territories
LCI	life cycle inventory
LCIA	life cycle assessment
MA	manually
MN	menu
IES	integrated environmental solutions
GHG	greenhouse gas emissions
GWP	global-warming potential
ELT	experiential learning theory
VLE	virtual learning environments
RVL	remote virtual lab
BIM	building information modeling
IAQ	indoor air quality
OSP	open-source platforms
PP	physical properties
MP	mechanical properties
CSIC	Consejo Superior de Investigaciones Científicas(Higher Council for Scientific Research)
CLI	command-line interface
TTN	The Things Network
MQTT	MQ telemetry transport/message queuing telemetry transport
AEC	architecture, engineering, and construction
GUI	graphical user interface

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