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LONG PAPER

Schools as living labs for the new European bauhaus

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Abstract
Societal values are strongly formed by public models; this is also true for buildings. It is easier to gain people's attention to the need for change, to significantly increase the quantity and quality of energy-efficient retrofits in Europe when public authorities and governments are adopting the appropriate approach. It is therefore important to demonstrate exemplary solutions at frequently used buildings like schools, universities, and science centers. Based on the concept of the Living Labs and the New European Bauhaus (NEB) initiatives, NEB–LAB initiative (www.eco2-schools.eu/) will work as a 'think and do tank' to co-create, prototype or even test new tools, solutions, and policy recommendations in the school settings toward more holistic or even challenging Whole–School Approaches. Hence, through the NEB—LAB, school communities will: (i) develop citizen awareness—raising activities spreading the concept of energy and resource—efficient building and renovating, and (ii) promote education and training for sustainability, helping all actors (school staff, students, families, citizens) development competences and positive behaviors toward an environmentally respectful energy use.

Keywords New European Bauhaus (NEB) · Education for Sustainable Development (ESD) · Living Labs (LLs) · Whole–School Approach (WSA) · European Green Deal (EGD)

1 Introduction

Sustainability issues are present in all aspects of our daily lives, including natural, technological, cultural, and social elements. Schools have the power to shape the attitudes, values, and actions of students toward a sustainable future because education is both mandatory and accessible to many children for a significant portion of their growth and development. The principle behind holistic approaches to Education for Sustainable Development (ESD) is that students can learn through both a formal curriculum and informally through the messages and meanings in their cultural surroundings. In this sense, education should aim to foster 'sustainability' and 'ecological citizenship', meaning to prepare active citizens (who can be innovative future entrepreneurs, decision-makers, pioneers and more). These individuals should possess a sense of responsibility and actively contribute to building a sustainable society [1]. It also means fostering a sense of pro-environmental behavior, encouraging citizens to minimize harm to their environment [2]. According to recent literature and reports, it is not the theory of ESD that has failed, but rather the educational pedagogies and curriculum in which it was placed [3].

However, although more education systems are implementing ESD, the awareness/values-action gap persists with fundamental flaws in many curricula, particularly in Southern European countries [3, 4]. One prominent problem is that most ESD current pedagogies focus primarily on the causes and effects of sustainability issues but fail to address the "how" and "where" of these issues, the strategies for change, and visions for the future. The struggle to effectively link content and pedagogy to behavioral change and sustainability citizenship in students suggests that ESD should explore different approaches. As ESD focuses heavily on skills development and competence-based curricula, impactful ESD that meets the needs of future sustainable societies cannot be confined to traditional content-oriented structures, teacher-centered learning, and formal curriculum spaces of education alone, but needs to draw on new formal, informal, and hybrid spaces that offer alternative possibilities for learning and action [5].

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In early 2022, a Proposal for Council Conclusions on learning for environmental sustainability[1] was presented by the European Commission Whole-School Approaches (WSA) to sustainability, incorporating all areas of activity that are not yet widespread. Such approaches can include teaching and learning; research and innovation; facilities and operations that should engage students, staff, parents, researchers, experts, and local and wider communities. Hence, WSA provides a framework for reorienting and redesigning education considering emerging global sustainability challenges. It refers to a holistic, systemic, co-creative, and reflexive effort by all stakeholders involved in education to meaningfully engage students in complex sustainability challenges.

The term 'holistic' highlights the attempt to explore and address sustainability issues from multiple perspectives in an integrated and relational way. Systemic refers to considering key aspects of the education system simultaneously (formal and informal education, curriculum, pedagogy and learning, professional development, school-community relationships, school practices, ethos, vision, and leadership). Co-creative refers to the inclusion of multiple voices and multiple stakeholders in the development of the approach within a given context. Lastly, reflexive refers to the need for continuous learning, monitoring, evaluating, and re-calibrating in light of a world that is in constant flux. Hence, a WSA is not a tool, a methodology or a prescription for implementing a topic or a specific agenda like ESD, but rather a means to encourage schools to use the WSA as a thinking tool for educational innovation generally [6].

Considering the school practices, ethos, and vision, the New European Bauhaus[2] (NEB) aims to bring together different disciplines and stakeholders to create solutions that integrate the principles of sustainability, aesthetics, and inclusivity into the built environment. Similarly, the WSA recognizes that education goes beyond the classroom and involves the entire school community, the school building, and the wider community. It emphasizes the importance of creating a supportive and inclusive environment that fosters creativity, critical thinking, and problem-solving skills. Both initiatives highlight the need to rethink and transform our current models of education and design to address the challenges of the future and build a more sustainable and equitable society.

In this sense, this paper indicates how co-creation approaches and the Living Labs (LLs) concept, linked to the NEB initiatives, have the potential to embrace innovative pedagogies as a progressive form to foster engineering approaches, innovation, and the strengthening of collaborative and participatory learning and planning. The paper has four further parts. Part One provides an overview of the NEB initiative, while Part Two highlights the need for renovation actions to the school buildings. Part Three and Part Four introduce the LLs concept and how it is linked to the NEB initiative to establish the NEB–LABS, respectively. At last, Part Five and Part Six draw conclusions on the pedagogical approaches to innovation that are relevant to workplaces and education today.

2 The new European bauhaus initiative

The NEB initiative, which started in January 2021, connects the European Green Deal (EGD) to our living spaces and experiences, expressing the EU's aim and desire to create beautiful, sustainable, and inclusive places, products, and ways of living. NEB calls on all of us to imagine and build together a sustainable and inclusive future that is beautiful for our eyes, minds, and souls. The initiative integrates design, ecology, social responsibility, and affordability, along with investments to advance the implementation of the EGD. The name of the initiative, inspired by the German arts and crafts school, Bauhaus, from the early 1900s, indicates a shared source of inspiration, driven by the urgency to adapt to social and technological changes occurring globally [7].

According to NEB's main pillars, buildings are an indispensable part of achieving the EU's carbon neutrality, energy efficiency, and renewable energy targets. Hence, the NEB plays a crucial role in creating interdisciplinary synergies to support innovative developments in the building sector. In this context, the European Energy Performance of Buildings Directive[3] (EPBD) required all new buildings to be nearly zero-energy buildings (nZEB) by 31 December 2020; however, the EU is not adequately delivering on its decarbonization and energy-efficiency targets for buildings. To achieve this, Europe needs to foster long-term, life cycle, and integrated thinking in the industrial ecosystem by increasing circularity to tackle unsustainable resource use and waste. Additionally, all European citizens must reconnect with nature, increase awareness and willingness to address climate change, reduce exposure to pollution, and regain a sense of belonging by building bridges between people and emphasizing the role of cultural and social assets as key factors in making places unique. To this end, NEB is creating bridges between different backgrounds, cutting across disciplines and building on participation at all levels,

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022DC0011.

[2] https://new-european-bauhaus.europa.eu/index_en.

[3] https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficient-buildings/energy-performance. buildings-directive_en.

inspiring a movement to facilitate and steer the transformation of our societies along three inseparable values:

- **Sustainability**, climate goals, circularity, zero pollution, and biodiversity,
- **Aesthetics**, quality of experience and style, beyond functionality,
- **Inclusion**, valuing diversity, securing accessibility and affordability.

Consequently, the NEB brings citizens, experts, businesses, and institutions together to reimagine sustainable living in Europe and beyond highlighting, among other key points,[4] that:

- **Societal values are strongly formed by public models**, this is also true for buildings. It is therefore important to demonstrate exemplary solutions at frequently used buildings like schools, universities, and science centers;
- Europe is dependent on having **high-quality education spaces accessible for all** for the future generations. The use of educational buildings as frontrunners will help to increase the market penetration of high-performance retrofit approaches. The 100% carbon-free school building must become the standard of the future;
- The qualities of a **zero-energy (or energy-positive) school, university or science center**, and the process required to create it can encourage learning (formal and informal), create healthy, high-performance learning environments, provide sound fiscal management of community resources, and demonstrate environmental leadership in minimizing the impact of the built environment;
- **Schools and educational buildings** in general can act as an incubator for innovation and creativity to drive sustainable design across Europe and beyond, that is also appealing and affordable for all citizens.

To further elucidate its goals, the NEB is currently overseeing a multitude of projects spanning across Europe. In particular, (i) in Denmark and the Municipality of Albertslund, a NEB project aims at transforming a former prison into a new liveable and green neighborhood, (ii) in Greece, the Municipality of Katerini proposal rests on redesigning the urban space of the city's center through extended water-permeable paving systems, natural materials, natural elements such as trees, shaping a new sustainable identity, (iii) in Portugal, the Municipality of Pampilhosa da Serra aims to define and implement a new policy mix for the villages of the cross-border EUROACE Euroregion, structuring catchment areas based on complementary network services and fostering new rural–urban relationships, and finally, (iv) in Spain, the city of Sant Boi de Llobregat in Catalonia focuses on the transformation of an existing building into an innovative education public facility which is intended to become a green, neutral-emissions building with a spirit of full circularity.[5]

Linked to the above-mentioned goals and NEB projects, the European Union plans to prioritize the modernization of existing buildings and spaces in the future, aligning with the Renovation Wave initiative of the European Commission within the EGD. By adopting a 'build less' strategy that emphasizes the optimal utilization and management of current resources, it may be possible to achieve an impressive 80% reduction in carbon emissions. This is in contrast to the 'build smart' and 'build efficient' approaches, which only offer reductions of 50% and 20%, respectively, and may not be sufficient to achieve the ultimate objective of climate neutrality [7].

3 NEB initiative and school buildings

Focusing on the school buildings current state, the European Energy Performance of Buildings Directive (EPBD) required all new buildings (public buildings from 2019) to be nearly zero-energy buildings (nZEB) by 31 December 2020. Already since 31 December 2018, new buildings occupied and owned by public authorities should be nZEB. This is a result of a long incremental regulation evolution starting with the EPBD 2010[6] and ending with the EU Directive 2018/844[7] of the European Parliament and the Council of 30 May 2018,[8] who amended the Directive 2010/31/EU[9] on the energy performance of buildings and the Directive 2012/27/EU[10] on energy efficiency. The nearly zero or very low amount of energy required should be covered to a very significant extent by renewable sources, including sources

[4] https://new-european-bauhaus.europa.eu/system/files/2023-01/NEB_Compass_V_4.pdf.

[5] https://new-european-bauhaus.europa.eu/get-inspired/inspiring-projects-and-ideas_en.

[6] European Parliament and Council of the European Union: Directive 2010/31/EU on the energy performance of buildings (recast). 2010. Available at http://eurlex.europa.eu/legal-content/EN/ALL/?uri=CELEX%3A32010L0031.

[7] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L0844&from=IT.

[8] Parliament E. Directive 2018/844/EU of the European Parliament and of the Council of 19 June 2018 on the energy performance of buildings (recast). Off. J. Eur. Communities 2018;61(156):75–91.

[9] https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2010:153:0013:0035:EN:PDF.

[10] https://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:315:0001:0056:en:PDF.

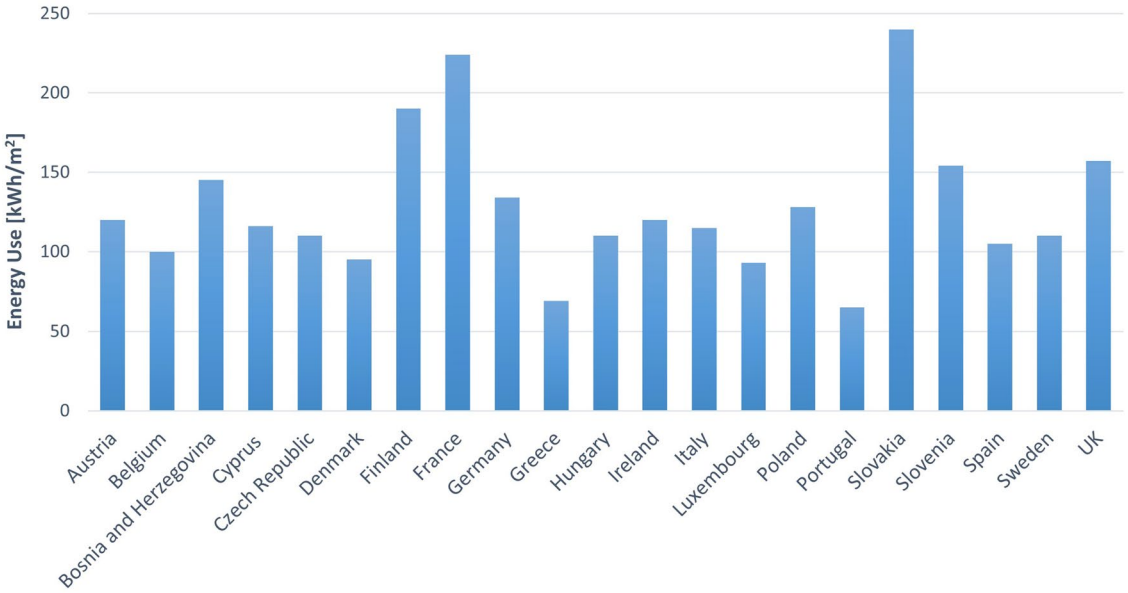

Fig. 1 Energy use of school buildings in European countries, [8–12] (varying from about 65 to 225 kWh/m^2 year)

produced on-site or nearby. For the building sector, this implies the large-scale deployment of nZEBs.

Combining renewable energy and resource efficiency can play an important role in the transition of the European society and economy toward sustainability and carbon neutrality.[11] According to Eurostat data (2018), the annual student population growth rate is expected to be around 3% until 2050. Before 2050, all member states will need to ensure a minimum floor area growth of 0.5%. This means that at least 4 million square meters of new classroom space. All these new classrooms need to be integrated into new schools in addition to the schools that need to be renovated require innovative energy-saving and indoor environmental quality solutions to demonstrate a commitment to reducing climate impacts, lowering energy cost, and over time saving money on energy bills that can be spent on almost 100 million students.[12]

Throughout Europe, most school buildings were built between the 1950s and the 1970s and are nowadays in need of renovation, including an energy upgrade. Many renovation projects focus on issues required by modern teaching styles. Others include the retrofit of building components and upgrades of building services systems components. In some cases, specific guidelines for energy-efficient building envelope renovation and building services systems updates are available. Some schools have "more ambitious targets" and go for a holistic energy retrofit that can reduce energy consumption significantly—like in the School of the Future project,[13] where different demonstration buildings aimed to reduce the delivered total energy to a third of the energy use before the renovation. Figures 1 and2 present the energy use of school buildings in different European countries and the thermal and energy consumption of 68 school buildings in Luxemburg [8–12].

Results indicate that increased variations occurred in terms of the total energy use in the European school buildings, which seems to be normal because of the different climate conditions between the Northern and the Southern European countries.

However, these examples show that many conclusions on energy consumption need to be regarded with caution, and a benchmark analysis is always necessary to know which types of buildings, geographical areas, boundary conditions, and energy indicators were used (i.e., thermal, heating or total energy consumption). Concurrently, Fig. 2 attests that when comparing standard to low-energy buildings, average thermal end energy consumption decreases by 36% and by an additional 52% for passive buildings.

The resulting energy use after the renovation is in the range of nZEB, the target for new buildings in the European Member States by 2021 according to the Energy Performance of Buildings Directive recast. In addition, the

[11] Attia S. Net Zero-energy Buildings (NZEB): concepts, frameworks and roadmap for project analysis and implementation. Butterworth-Heinemann; 2018.

[12] Lanniello E, d'Ambrosio Alfano FR. WS10: The REHVA guidebook on indoor environment and energy efficiency in schools–Part 1. Principles. REHVA J 2010.

[13] https://school-of-the-future.eu/.

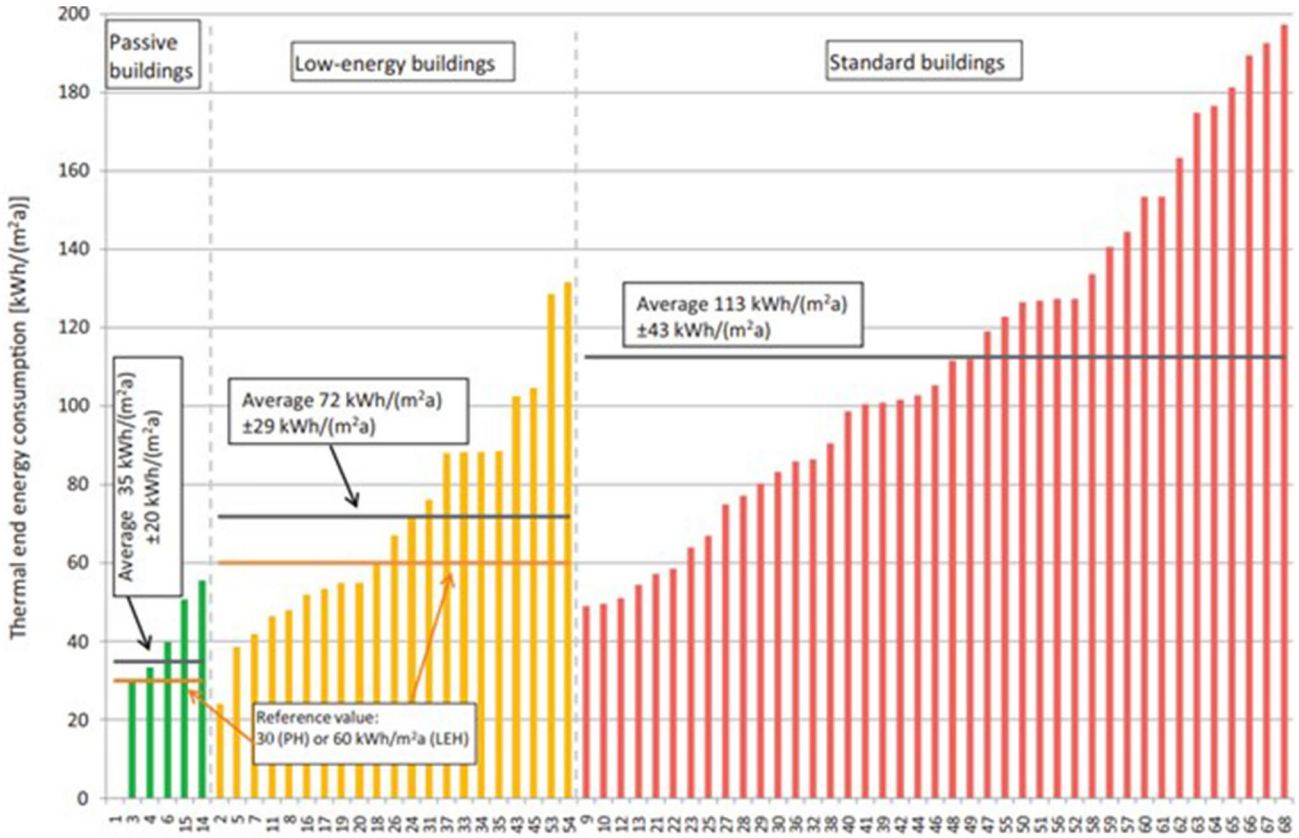

Fig. 2 Thermal and Energy Consumption of 68 School Buildings in Luxembourg, [9] (Standard, Low-Energy and Passive Buildings)

European Directive 2012/27/EU[14] directs the member states to develop an intensive refurbishment of public buildings. Schools represent an important part of public building stock and, even if they are not a predominant percentage of the total public patrimony, their refurbishment represents an important issue, both for social and educational aspects.

It has to be noted though that the national application of the nZEB definition differs from country to country and is not yet fixed for all EU Member States. Hence, the EU has launched the Level(s) framework[15] to bring buildings into the circular economy. The framework encourages lifecycle thinking and supports users from the design stage through to operation and occupation of a building. Level(s) focuses attention on the most important aspects of a building's performance, providing a simple entry point to what can be a very complex area. Building professionals and their clients can use Level(s) to increase their understanding of how buildings impact on the environment. Level(s) helps the user identify hotspots and shows how to reduce environmental impact. Most EU Member states have already defined the values and the criteria based on Level(s).

The European Climate Law,[16] voted on 28 June 2021, introduces a systemic changeover with the target of reaching at least -55% CO_2 emissions / energy / resources / transports consumption in 2030 (- 6% better each year). The FIT FOR 55″[17] legislative package, that transposes this European Climate law into the national regulations, will impose a European renovation wave that will concern almost all existing buildings. This induces four (4) dimensions of change of posture considering existing offers and habits:

- **Footprint reduction:** Transitioning to renewable energy is one of the most powerful ways for countries to reduce their Ecological Footprint and significantly reduce the consumption of energy-resources with qualitative retrofitting in a circular approach;

[14] The European Parliament. Directive 2012/27/EU of the European Parliament and Council of 25 October 2012 on Energy Efficiency; The European Parliament: Strasbourg, France, 2012.

[15] https://ec.europa.eu/environment/topics/circular-economy/levels_en.

[16] European Climate Law.

[17] FIT FOR 55″ legislative package.

- **Nearly zero-emission buildings:** Make the existing buildings 'Net zero consumers' with renewable energies in self-consumption;
- **Restoring nature:** Be prepared for rising temperatures, heat waves/storms, seasonal water shortages with smart adaptation to the urban environment;
- **Environmental Handprint**: This induces a deep change in behavior (knowledge, offers, and habits), with a rising need for lifelong Education involving three generations in cooperation, for achieving a learning by doing process sustainable global performance, in continuous improvement.

Highlighting these dimensions, the creation of zero-energy or energy-positive educational facilities, such as schools, universities, or science centers, involves a process that can promote formal and informal learning, foster healthy, and high-performing learning environments, ensure responsible fiscal management of community resources and showcase sustainability leadership by reducing the impact of the built environment. In light of energy efficiency and renewable energy technology that is changing rapidly, what was not financially or technically achievable a few years ago is feasible today and likely largely replicable in the next years. To this end, educational buildings hold great potential as innovation incubators and catalysts for sustainable design that is both attractive and affordable to everyone.

4 Co-creation approaches—the living labs concept

Bringing and bridging different societal actors and transforming educational spaces into innovation incubators, as the NEB indicates, is a complex scheme. In this context, design principles and practices constitute a potential field for creative innovation and support for promising initiatives on sustainability, offering competences, abilities, methodologies, and a unique viewpoint. Weighting in the 'co-creative' aspects, the Living Labs (LLs) concept consists of a co-creative design offering an environment that aims to facilitate co-creation as an interactive scheme for collaborative research where multiple users play an active role [13].

The LL methodology is issue-driven and exists within rich, complex, and contested real-world problems and challenges [13, 14], that of sustainable living. To this end, the theoretical basis for the co-creation methodology is transdisciplinary, in broader terms, defined as the attribution of knowledge from science in an issue-driven process [13, 15]. The concept of LLs was introduced in academia in the 1990s by American scholars and proliferated in Europe from 2006 onwards when the European Commission started promoting the concept as part of its innovation policies. LLs are part of a broader family of laboratories that are operating in a real-world context (Urban Labs, Transition Labs, and Challenge Labs) and employing innovative approaches for the co-creation of technology, products, and services. As such, they have roots in user and open innovation studies. In this context, LLs have emerged as a response to such needs and as research platforms for sustainable product and service innovations [16]. Correspondingly, many LLs are paying attention to the United Nations (UN) Sustainable Development Goals (SDGs) [14].

Considering this, the European Network of Living Labs (ENoLL), an umbrella organization for LLs, defined these schemes "user-centered open innovation ecosystems based on a systematic user co-creation approach, integrating research and innovation processes in real-life communities and settings".[18] Openness (gathering many stakeholders from various domains with various expertise and competence), continuity (establishing trustful long-lasting relations between stakeholders), empowerment (enabling users to actively be engaged in the innovation process), realism (involved with real users in real-life settings during the development of the innovation), and spontaneity (detecting and analysing emerging need and ideas of stakeholder) are the key LLs principles.

Considering this common shared vision and the LLs characteristics and purpose, to face the youth's current and future challenges, it is essential to invest in creating new scenarios and lifestyles, strengthening students' and citizens' knowledge, skills, and attitudes. In this context, design-based participatory processes are suited to support youth development and empowerment as long as they: (i) provide spaces for experimentation, inviting youth to reflect and enact choices in a non-serious, playful environment; (ii) offer opportunities for peer interaction, equal participation with adults, exploration of diverse identities, and elaboration of possible futures; and (iii) improve youth's ability to understand and contribute to (trans)forming their life contexts, exercising skills for active participation and positive intervention. Thus, education has an important role in the process of transition toward sustainability, offering experiences for students to gain knowledge, develop skills, and cultivate attitudes and awareness of socio-economic and environmental responsibilities [14].

Regarding primary and secondary education, a representation of schools as LLs is too limited. According to Windeløv-Lidzélius [17], there is a multitude of educational setups that may appear similar on an overall level, but on a more practical level are quite different. It could be helpful for schools, in general, to understand how to better include, for instance, stakeholders wanting to test out the technology,

[18] https://enoll.org/about-us/.

as well as how to go about being an innovation hub for the school community and the broader society. As such, concrete ways to approach science education programs by fostering collaboration between schools and local communities, based on LL methodology and open innovation in Europe, are needed more than ever. Toward this pathway, several efforts are proposing to transform schools into LLs by adopting the concept of open schooling,[19][20] in science education.

In the 'Schools as Living Labs' (SALL[21]) project, the LL methodology is proposed as a new technique for the development of open schooling activities linked to science learning. Within the SALL project, 'Living Lab' is the methodology used to support the collaboration among different partners who want to address a concrete issue relevant for each of them, going through a LL cycle typically comprising of: (i) creating ideas together after exploring the issue, (ii) quickly building some elements of the solution, which can be done in a cheap and fast way (often referred as prototyping), and finally, (iii) testing the solution with users, and getting feedback to improve the solution. This cycle may be implemented several times, iteratively, to refine the solution at various levels. The key principles are [18]:

1. **Co – creation** and analysis including identifying needs, defining issues, and coming up with ideas and a real solution, making use of the participants' personal experience;
2. **Exploration** and quick prototyping, as ideas, are immediately put into practice and tested;
3. **Experimentation** by testing the prototype or scenario of the solution in real life and finally;
4. **Evaluation** by analysing the results of the experimentation to validate or improve the solution.

In the steps mentioned above, the central players are the school communities by initiating and participating in the co-design processes. Thus, schools were systematically engaged in the work of a project, involving students, teachers, and student's families in the processes of dialogue, mutual learning, and co-construction. As revealed from the project outcomes,[22] teachers were more involved in the project planning and conceptualization process and more eager to express and reflect on aspects (of internal and external origin) that could facilitate or hinder the successful implementation of their school project.

5 From the schools as living labs to the NEB–labs

Moving a step forward from the schools as LLs, NEB–LABS is considering schools as 'learning organizations' and 'core social centers'.[23] Schools should provide a place for the pupils to gather, interact with others, and learn about diversity. As Carvalho et al. [19] highlight, this sentiment was expressed by van Eyck in 1962, emphasizing the importance of creating spaces where children can be themselves. Van Eyck's words advocate for openness, inclusivity, and freedom in the spaces where students spend their time, recognizing that this is not only vital for their education but also for their future lives. The problem of educational spaces, as presented to the students, stems from a reflection based on the words of educational reformer Ken Robinson, according to whom teachers are like gardeners [20]:

> Since 'plants grow themselves,' then what good teachers can do is to create the conditions for learning.'

In addition, when considering the LLs concept and ESD, the Dutch DuurzaamDoor,[24] a government initiative established in 2017 and executed by the Netherlands Enterprise Agency promoting the WSA and the engagement of stakeholders in the education process highlighted that: *'the whole school approach to sustainability brings together what is taught, how it's taught, extracurricular activities, teacher training, decision—making processes, the physical buildings, the environment and the whole community'* [20]. The key point in this statement is that since societal values are strongly formed by public models; this is also true for buildings. Based on the concept of the school LLs and the NEB initiatives, NEB—LABS work as a 'think and do tank' to co-create, prototype or even test new tools, solutions, and policy recommendations in the school settings. Hence, the NEB—Labs are able to facilitate the transformation of the pilot sites to innovation hubs in their communities, raising citizen awareness activities to facilitate social innovation, promoting education and training for sustainability, conducive to competences and positive behavior for a resource-efficient and environmentally respectful energy use.

Through the NEB—LABS, school communities will: (i) develop citizen awareness—raising activities spreading the concept of energy and resource-efficient building and renovating, and (ii) promote education and training for sustainability, helping all actors (school staff, students, families, citizens) development competences and positive behaviors toward respectful and environmental-friendly energy use.

[19] https://www.openschools.eu/.

[20] https://openscienceschooling.eu/.

[21] https://www.schoolsaslivinglabs.eu/.

[22] https://www.schoolsaslivinglabs.eu/wp-content/uploads/2022/02/SALL_D5.2_Interim-report_final.pdf.

[23] https://www.oecd.org/education/school/school-learning-organisation.pdf.

[24] https://www.duurzaamdoor.nl/.

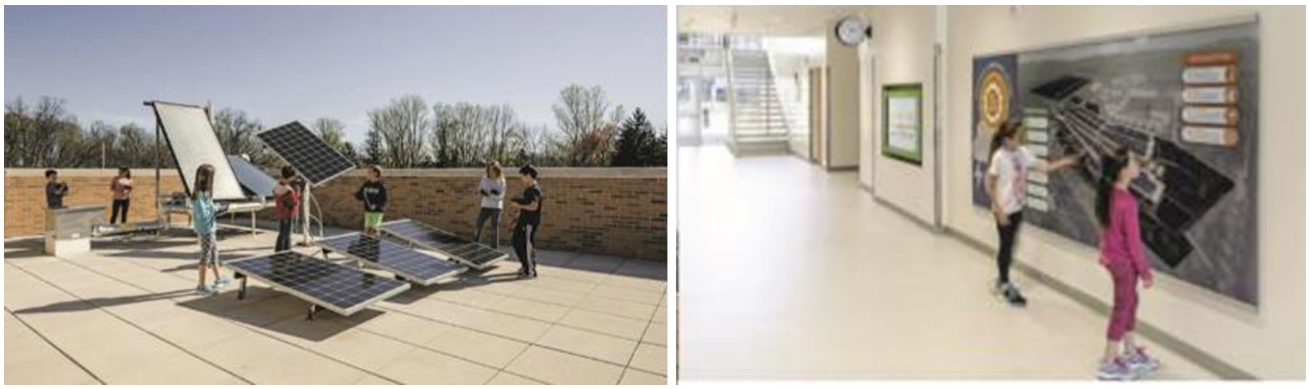

Fig. 3 Renewable Energy Labs (left) and Interactive Energy Dashboards will be used to facilitate the building's development (right)

To this end, the main contributions of this concept include a primer on how to: develop and deliver the pathway through which schools can become a physical place of education and knowledge, (ii) propose ways of learning or gaining knowledge and/or the education and pedagogical focus for effective integration of these topics to the curriculum and finally, and (iii) re-consider the relationship of the schools with the local communities as hubs of innovation toward the green transition and sustainable development.

Both of these concepts, NEB—LABS and LLs are envisioning that these solutions are seen as being more sustainable, cost–effective, and resilient than traditional engineering solutions. Nevertheless, the transformation of places of learning that connects a tangible place with innovative pedagogical methods and the local communities is a quite complex learning ecosystem. However, such a vision might be a tipping point where the ways the schools live and breathe sustainability while maintaining a critical and flexible mind, becomes the new normal.

Examining these spaces are closely intertwined with the heart of both the SDGs and the NEB, which incorporates various initiatives, including the reconsideration of learning and teaching models, such as the function of physical spaces for learning, the connection with the community, and fresh approaches to learning [20]. Building on these ideas, it has been agreed upon more recently that the right spatial articulation in schools offers the opportunity for hosting different activities. Education is a constantly evolving field with changes in pedagogy, technology, instructional programs, and enrollment, making it necessary for educational environments to be adaptable to constant change with minimal disruption and cost. On the other hand, indirect measures to improve learning environments such as indoor air quality, thermal and visual comfort, daylighting, and technology infrastructure for low zero-energy buildings must all consider this need for adaptability. Thus, NEB—Labs will showcase innovative approaches and solutions, with the common goal of creating a building that promotes inquiry-, problem– and project-based learning and a sense of ownership among students and building stakeholders.

6 NEB–labs in action–exemplary cases

Linking education and zero-energy, by involving students, teachers, school administration, parents, and community members, can foster a sense of ownership and promote a long-term commitment to sustaining zero-energy performance. To promote active participation and deeper learning about energy production, consumption, and efficiency, innovative installations can be implemented during the renovation phase to enable each new cohort of students to witness the creation of a zero-energy school (Fig. 3).

Delving into the NEB–LABS in action, interactive energy dashboards can provide students with a dynamic understanding of the school's energy-efficient features and how they operate in different weather conditions. Similarly, creating a portal to showcase the school's inner workings can foster pride and a collective sense of responsibility for the environment. Also, the equipment usually found in school buildings includes electronic boards, TVs, computers, monitors, printers, copiers, cooking facilities, and smaller devices such as coffee machines, kettles. In principle, primary schools, large secondary schools, universities, and science centers are hosting canteens and restaurants that include ovens and refrigerators that are rather consuming facilities. In this context, energy consumption monitoring campaigns and energy audits may be tested. For instance, experiments with an electricity meter can make the pupils aware of the stand-by energy use or the installation of timers to program the automatic shutdown of the devices after school hours is an effective measure. Thus, renewable energy labs and site-prospecting projects to install photovoltaic panels or small–scale wind turbines at school may constitute part of the curriculum or the extra-curricula activities.

Fig. 4 Toward a Real-Time Understanding of the climate and environmental conditions (left), energy and material Flows, ICTs and BIM—enabled mobile mixed reality visualization of heating and ventilation pipes (right)

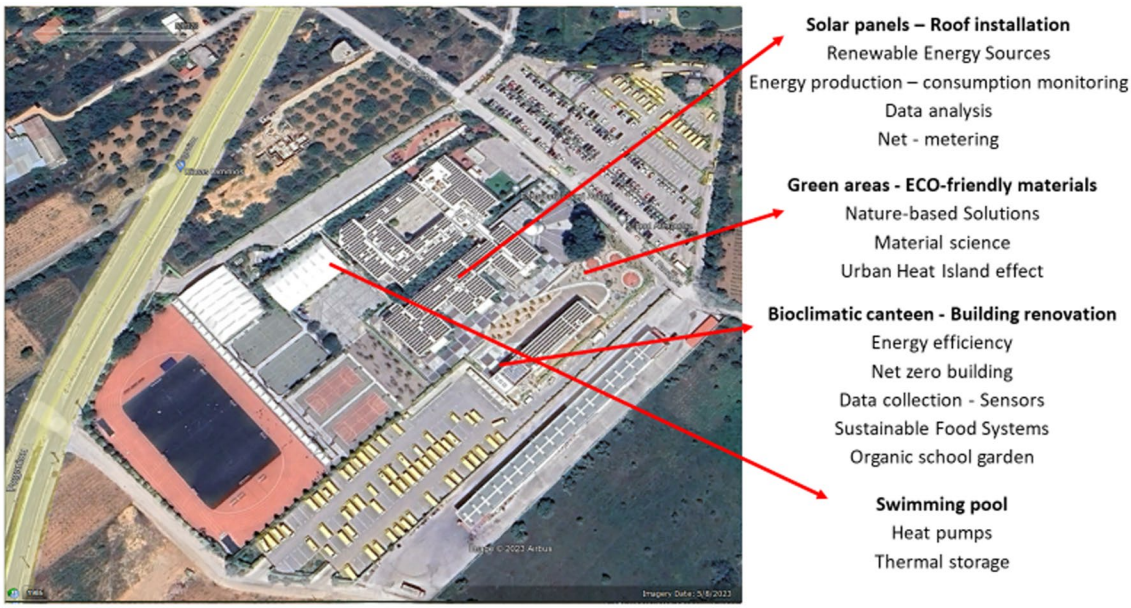

Fig. 5 Taking advantage of the renovation and restoration activities to introduce innovative topics and experiential learning at schools

Addressing more advanced concepts and seeking emotional connection with the environment and our learning spaces, through the use of Augmented Reality (AR), Virtual Reality (VR) and Mixed Reality (MR) technologies students will be given a brand-new view of their school building, the surrounding areas, and their neighborhoods. One of the most important characteristics of these technologies is the creation of the immersive feeling of 'being in the real world'. Through the interaction between students and devices, they can truly experience the existence of the virtual environment (see Fig. 4). In particular, the application of AR technology in landscape scene construction makes up users' experience of uncompleted landscape design and creates a new way for a designer to explain the project [21]. Moving a step further, the concept of a Smart Urban Metabolism (SUM) is to provide knowledge on energy and material flows as close as possible to reality by collecting and analysing real-time user-generated data sources (see Fig. 4). Hence, ICT infrastructure is used to collect data on energy and material flows from utilities, and sensors and smart meters are installed in households, businesses, and public spaces [22].

The overarching goal of such actions is to engage students in the monitoring, planning, and renovation processes. The scope is to engage pupils in these processes by collaborating with external experts, researchers, and different societal actors to promote the school's vision. In this context, students, and overall, the entire school community appreciate how they are an integral part of the system.

In this sense, different renovation projects may act as the main drivetrain to build different types of activities linked

to the curriculum, extracurricular activities, skills labs, etc. For example, at Ellinogermaniki Agogi[25] school in Greece, the bioclimatic canteen building is part of the school strategy toward the transformation of food systems that require low-carbon, circular, and planted-based approaches. The school operates an organic school garden that apart from acting as an open educational environment for all students is producing a significant amount of vegetation being consumed in the school canteen. The building-embedded photovoltaics (links to the renewable energy labs mentioned above) will generate enough renewable energy on–site to cover 100% of its energy needs on a net annual basis. A heat pump will be used to cover the refrigeration requirements and the heat demand.

The school stakeholders aim to transform the canteen into a learning hub for the students to test solutions for reducing energy, water use and for interacting with the food systems. Through making these efforts highly visible, this leadership inspires a larger movement that significantly accelerates the adoption of a sustainable lifestyle—first around energy, but also other critical areas like sustainable food systems, use of resources, Nature-based Solutions, material science, and relationship to the natural world. A visual representation of how to take advantage of such renovations to introduce such topics linked to the curriculum is illustrated in Fig. 5.

In addition to the building design influences to introduce different innovative topics indicated in the previous paragraphs, the building envelope quality has a huge impact on the students' and teachers' performance. Thus, the use of classrooms and in general the learning and teaching environment must nowadays be more flexible. The original teaching form with the teacher up front and the students directed to him/her in rows is used less and less today. Working groups, animated learning, and individual learning time often connected to the use of computers take over and result in flexible table and chair positioning or even new sizes and equipment in classrooms. On the other hand, some of the boundary conditions for classrooms will remain (i) enough space for up to about 20–30 pupils, (ii) high ceilings to provide suitable air volume and together with large window areas placed mostly on one side of the classroom, (iii) enough daylight, rather high artificial lighting installations to compensate the daylight in the early and late hours or winter, etc., (iv) floors, walls, and ceilings need to be covered and painted with healthy (non-toxic) materials and finally, (v) the indoor temperatures and thermal comfort, indoor air quality, noise, etc., have to be maintained at a good level.

In conclusion, experiences so far with the NEB in educational settings have been positive, however, they are rather sparse. In some countries, schools have incorporated the principles of the initiative into their curriculums, offering courses on sustainable architecture, urban planning, and design, among other topics [7, 23]. Additionally, many schools have started to use the NEB principles as a way to engage students in community-based projects that aim to promote sustainability and civic engagement through the LLs concept. By building on the concept of WSA (Designing project-based, experiential learning led by schools with parents, local businesses, and the wider community), schools will be able to develop concrete and replicable climate action plans to be transformed into innovation hubs in their communities. These partnerships should be based on the principles of equality and mutual learning and relevant policy-makers play a vital role in encouraging policy buy-in and mainstreaming good practices and insights into policies, thus ensuring sustainability and impact.

To succeed this, first and foremost, providing training and capacity-building programs for the school administration and overall, the school staff on sustainability principles, the benefits of sustainable learning spaces, mobility and networking actions, funding allocation, and re-skilling programs is crucial. Additionally, leveraging existing communities of practice and networks can help overcome challenges in schools by facilitating the sharing of sustainable solutions and providing collaborative platforms for co-creating common climate action plans. These partnerships also unlock funding opportunities, as existing networks, including educational institutions, local governments, non-profit organizations, and businesses, allocate resources such as funding, expertise, and research to support these interventions. However, such renovation projects are costly and hard to be maintained, thus, exploring options like public–private partnerships and engaging with local organizations can help secure the necessary resources for these initiatives. Another potential challenge lies in stakeholder resistance to change, especially when it involves altering traditional educational practices. Addressing this resistance requires engaging in meaningful dialogue, sharing success stories, and involving stakeholders in the planning process to foster understanding and support.

Overall, as the initiative continues to gain momentum, it is expected that more schools will adopt these principles, which will lead to a greater understanding of sustainable design practices and increased awareness of the role architecture and design play in achieving a more sustainable future.

7 Conclusions

In conclusion, the NEB initiative has immense potential in educational settings and schools. The initiative's focus on combining sustainability, aesthetics, and functionality

[25] https://www.ea.gr/ea/main.asp?id=102&lag=en.

aligns well with the current priorities of modern education, where the emphasis is on promoting environmental consciousness, creativity, and innovation. By introducing the principles of the NEB into the school curriculum, students can be exposed to sustainable design practices and most importantly to critical environmental issues for contributing to a more sustainable future. Furthermore, integrating the NEB principles into educational settings can provide an opportunity for schools to become more environmentally conscious by using renewable energy sources, employing sustainable building practices, reducing their carbon, environmental and ecological footprint, and overall, fostering a culture of sustainability. To this end, the NEB–LABS concept has the potential to be a game-changer in education and schools. It provides a new framework for sustainable design and innovation that aligns with the needs of modern society.

The study emphasized the importance of rethinking education, our learning environments, and their connections, to promote innovation and participatory design thinking in conjunction with the NEB initiative and the LLs concept. It suggests that NEB–LABS may cultivate active participation, deeper learning, and overall, STEAM education, with their holistic and transdisciplinary approach, by fostering innovation, developing competences, and preparing young people to tackle different sustainability challenges. However, some concerns are noted about the actual practicability of such efforts. WSAs and the LLs concept, to the authors' knowledge, consist of the ideal schemes to introduce such initiatives, nevertheless, the success of these approaches is dependent on effective communication, collaboration, and engagement with all stakeholders, which can be challenging in a complex and diverse educational setting. Overcoming these barriers will require a concerted effort from all education stakeholders, including educators, students, parents, and policy-makers, to support adoption and implementation.

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Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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