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Book of abstracts

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NAWA POLISH NATIONAL AGENCY FOR ACADEMIC EXCHANGE

INTERNATIONAL CONFERENCE INNOVATIONS IN BUILDING DECARBONIZATION AND ENERGY SYSTEMS

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Dorota Anna Krawczyk, Anna Justyna Werner-Juszczuk

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Dear Readers

It is our great pleasure to present the Book of Abstracts of the Innobuild Conference, bringing together a diverse and international community of both experienced researchers and early-career scholars at the beginning of their academic journey. By combining experience and knowledge with fresh perspectives, we hope to foster meaningful exchange of ideas and inspire new, creative approaches.

The contributions included in this volume reflect the current challenges and emerging directions in the built environment, with a strong focus on sustainability, innovation, and interdisciplinary collaboration. The wide range of topics demonstrates the dynamic nature of the field and the importance of integrating technological, environmental, and societal perspectives.

We would like to sincerely thank all authors for their valuable contributions, as well as the reviewers and organizing team for their commitment and support in preparing this publication.

We hope that this Book of Abstracts will inspire further discussion, foster new collaborations, and contribute to advancing knowledge in the field.

Editors
Dorota Anna Krawczyk,
Anna Justyna Werner-Juszczuk

A future of healthy buildings. Are we there yet?

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A healthy building does not compromise the basic human needs of every building occupant and fosters a high quality of life, good health, optimal physical and mental activity, and high-quality sleep. The newest definition, proposed in 2024, identifies five features indispensable for achieving healthy building structures. These are: (1) improving mental and physical health; (2) designed for human needs; (3) sustainably built and managed; (4) resilient and adaptive; and (5) empowering people.

The latest revision of the Energy Performance of Buildings Directive (EPBD) emphasizes, for the first time, the importance of indoor environmental quality. The new and retrofitted buildings must meet specific criteria to ensure that the carbon footprint and the health and comfort of building occupants are not compromised. It thus sets energy and indoor environmental quality on a par, opening a clear path towards the quicker realization of a healthy building concept. The question is whether we are prepared for this activity.

In the last few decades, numerous studies have shown that high indoor environmental quality improves the health, well-being, comfort, work performance, learning, and sleep quality of building occupants. We thus have a strong theoretical background and should be able to realize the healthy building concept. So, what is limiting the implementation?

Despite the strong theoretical background, the infrastructure and solutions are missing for the full implementation of the healthy buildings concept. These include, among others, monitoring and affordable solutions that can be easily retrofitted. One crucial constraint is a lack of awareness. Economic calculations are showing significant benefits, yet the arguments are not perceived as sufficiently strong or convincing. One problem is that healthy buildings are often considered to additionally contribute to carbon emissions and directly impact climate change. It is therefore necessary to show that healthy buildings can contribute to decarbonization: improving health can significantly reduce the carbon footprint of health care.

In the future, other features of healthy buildings could be considered, such as their ability to enhance health (salutogenic design) and to capture and store carbon, among others.

Grid services in Smart Energy Systems provided by consumers: Opportunities based on demand management strategies in buildings

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The ongoing transformation of energy systems is driven by three interconnected pillars: the electrification of demand, the decarbonization of energy supply, and the large-scale integration of renewable energy sources. These trends are reshaping the structure and operation of power systems, increasing their complexity while simultaneously creating new opportunities for efficiency and sustainability. Within this evolving framework, consumers are no longer passive recipients of electricity but are becoming active participants whose behavior can significantly influence system performance and stability.

Once consumers have implemented energy efficiency measures to their maximum practical extent, further reductions in energy costs and environmental impact depend on the adoption of demand management strategies. These strategies enable consumers to adjust their consumption patterns in response to external signals such as price variations, grid conditions, or contractual incentives. Demand management is inherently linked to the concept of flexibility, defined as the ability of consumers to modify the timing, intensity, or location of their electricity use without compromising core functionalities.

The flexibility provided by consumers constitutes a valuable asset that can be harnessed by multiple actors across the energy system. For system operators, demand-side flexibility can support the provision of ancillary services, including frequency regulation and voltage control, thereby contributing to the secure and stable operation of the grid. At the distribution level, flexibility can help address local technical constraints, such as congestion or voltage deviations, deferring or even avoiding costly network reinforcements. Additionally, energy retailers and aggregators can leverage consumer flexibility to optimize portfolio management, improve forecasting accuracy, and reduce imbalance costs in electricity markets.

In this context, demand-side flexibility in buildings emerges as a key enabler of the energy transition. By allowing building occupants and energy management systems to actively adjust consumption – through heating, cooling, ventilation, lighting, and appliance control – buildings can play a crucial role in supporting system operation. This flexibility facilitates the integration of renewable energy by aligning demand with variable generation, reduces overall system costs by shifting or shaving peak loads, and enhances grid reliability by providing distributed support services. Consequently, unlocking and effectively utilizing flexibility in buildings will be essential for achieving a sustainable, resilient, and decarbonized energy future, particularly given the significant share of energy consumption attributed to the building sector.

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International experiences in engineering education and science

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In an increasingly globalized economy, engineers and scientists are expected to collaborate effectively across national, cultural, and disciplinary boundaries. Multinational corporations and international research teams now define much of the technical landscape, yet many engineering and science programs continue to educate students primarily within local or national contexts. This talk argues that intentional international experiences are an essential component of educating the next generation of the technical workforce.

The presentation draws on more than eight years of sustained international collaboration in engineering education, beginning with long-term project-based partnerships with Linköping University in Sweden and expanding to include universities in Spain, Ghana, Uganda, and Bialystok University of Technology. These collaborations pair students from partner institutions into mixed international teams working on shared design challenges, requiring them to integrate engineering practice with scientific reasoning, data analysis, and evidence-based decision making while navigating differences in academic culture, communication styles, and expectations.

The current two-year collaboration between Bialystok University of Technology and the University of Colorado, Colorado Springs is presented as a focused case study within this broader framework. Lessons learned across multiple countries and institutional contexts will be discussed, including effective project structures, common challenges faced by students and faculty, and observed impacts on student engagement, professional confidence, and global technical awareness. The talk concludes by positioning international, project-based collaboration not as an enrichment activity, but as a necessary element of modern engineering and science education in a global economy.

The impact of climate change on energy consumption in buildings

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Climate change over the past decades has affected life around the world. Since buildings substantially contribute to carbon dioxide emissions and energy use, this study analyses how weather conditions have affected buildings' energy consumption over the past 50 years and underscores the importance of retrofitting actions.

A dynamic analysis was conducted for a hypothetical single-family house located in three European cities characterised by different climatic conditions. The experimental climate data for the considered sites over the past 50 years show significant variations, setting the stage for anticipating future environmental challenges and preparing adaptive strategies to mitigate the impacts of climate change.

The simulated building features a multifunctional heat pump system that provides heating, cooling, and domestic hot water (DHW). The analysis indicates that, over the years, the total electricity demand has increased or decreased, depending on the city's climate. Something certain: all the cities under investigation show a rise in cooling demand during warmer summers and a decrease in heating requirements during milder winters.

The findings suggest that, across all cities, the energy required to cool residential spaces is expected to increase. As a retrofit measure, the study analyses the effect of installing on-site photovoltaic (PV) panels. They help meet the building's overall electricity demand, thereby reducing its dependence on the electrical grid. The integration of PV can improve resilience during grid outages, lower operating costs over the system's lifetime, and help decarbonise the building's energy profile.

A. HVAC SYSTEMS, THERMAL COMFORT & INDOOR AIR QUALITY

Impact of natural ventilation on dynamic energy model calibration in a nZEB educational building

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In recent years, educational buildings have undergone extensive energy retrofitting processes, often involving the installation of Building Management Systems (BMS). These systems monitor a large number of variables, going well beyond the mandatory sub-metering of energy consumption.

The collected data can therefore be profitably used to develop digital twins that accurately reproduce the actual energy behaviour of buildings. Among these, dynamic energy simulations are widely used to evaluate the energy performance of buildings in variable conditions, as well as to design energy management and flexibility strategies. However, the accuracy and reliability of these models depend heavily on proper calibration and validation. In particular, calibration involves adjusting the model's key input parameters, which are influenced by the occupants' behaviour, such as opening and closing windows and shutters. These factors significantly impact ventilation airflow rates and solar gains, which are key drivers of heating and cooling demand, respectively, in well-insulated buildings. Moreover, occupant-driven window opening plays a crucial role in ensuring adequate indoor air quality (IAQ), which is a priority given its well-documented effect on students' health and cognitive performance.

This work presents a calibration procedure based on monitored indoor temperatures in classrooms to estimate ventilation and infiltration airflow rates. The aim is to assess the air changes per hour (ACH) in a naturally ventilated school, both to infer the IAQ conditions and to improve the calibration of a dynamic energy model. The proposed methodology is applied to a nZEB primary school located in Italy. A coupled simulation approach is adopted, combining the multizone airflow model CONTAM and the dynamic energy simulation tool TRNSYS. CONTAM is used to model infiltration and natural ventilation phenomena, accounting for building air-tightness, occupant-driven window opening behaviour, and local wind conditions. The resulting airflow rates are then integrated iteratively into the TRNSYS energy model to assess comfort and thermal energy consumption. Data collected in 2024 was used. A multi-stage calibration procedure was carried out, considering different operating conditions and seasons, such as free-floating/heated conditions and in the presence/absence of occupants. The results demonstrate that explicitly modeling ventilation and infiltration significantly improves the dynamic energy model. The root mean square error (RMSE) for indoor air temperature was below 0.5 K for all monitored classrooms, indicating a good agreement between simulations and measurements, with satisfactory agreement for the thermal energy consumption at the building scale. Natural ventilation rates were below 10 L/s per person, indicating critical IAQ conditions in several classrooms.

Automated AHU diagnostics based on BMS data analysis

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In modern public buildings ventilation becomes one of the main energy consuming systems. Numerous studies show that ventilation systems often operate inefficiently due to inadequate control strategies, poor system management or faults detection resulting in avoidable energy waste. Air handling units (AHUs), as the "heart" of the system, play a crucial role in building energy performance and indoor air quality. In practice, however, their operation is often suboptimal due to inaccuracies in control logic, inappropriate setpoints, or sensor errors, leading to unnecessary energy use. The aim of this study is to develop and apply a practical, data-driven tool for automated AHU operational diagnostics using building management system (BMS) operational data.

The proposed approach combines time-series pre-processing, operating-hours filtering, and data aggregation into fixed 30-minute intervals with a set of physically interpretable diagnostic indicators. These include supply-air temperature setpoint tracking, seasonal temperature-difference (ΔT) analysis, heat-recovery efficiency evaluation, airflow and CO_2 control interactions, and heating-water valve behaviour assessment. The aggregated energy waste score (EWS) is presented with a scale from 0 to 100. The index includes four sub-indicators based on rules, which show the most common types of energy loss in the AHUs: (i) the air supply temperature is too high or low (±1 °C), (ii) the fan is running when CO_2 level is low, (iii) the pressure is too high, and (iv) the air is being heated and cooled at the same time. Each sub-indicator is calculated as the proportion of operating time during which inefficiency conditions occur. The final EWS is obtained by combining these components with equal weights in the basic variant. The resulting score allows to evaluate the actual AHU performance, and use it for data-driven diagnostic. The system also automatically generates insights and recommendations to support operational decision-making.

The methodology is implemented as an interactive diagnostic tool developed using Python and Streamlit and applied to real-building AHU data. The results show low supply-air temperature tracking accuracy (42.4%) and increased pressure losses, while the overall Energy Waste Score remains moderate (18.7/100). The tool demonstrates that operational BMS data can be systematically transformed into clear, actionable insights and highlight the method's potential for continuous ventilation-system optimization and energy savings, and supporting building energy managers in promptly diagnosing AHU performance.

Adaptive comfortable space for living for a modern person: A puzzle of eco-solutions, traditions and natural elements

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Modern urban development has given rise to high population mobility and an increasing demand for individual comfort and the need for rapid adaptation of housing to various climatic, spatial and social conditions. In this context, the search for meanings and means that would make it possible to organize highly adaptive and safe housing and living areas close to humans is relevant.

The purpose of these studies is to substantiate the prospects for the construction of new housing based on adaptive and nature-integrated principles. Their implementation was due to the current processes of transformation and modernization of the urban environment. The proposed approaches are universal and suitable for the formation of new urban areas and the renewal of existing buildings. Their conceptual basis is based on the paradigm of "return to nature", which is understood as the integration of materials and design strategies that contribute to favorable microclimatic conditions, stable physical parameters and psychological perception of naturalness in the living environment. The methodology combines experimental testing of materials and comparative analysis. Concrete composites containing eco-inclusions and natural nano-fillers were developed and evaluated. These fillers included natural minerals such as zeolite, as well as crushed wood particles and dry biomass of wild herbaceous plants. Laboratory tests evaluated the moisture management capacity, heat storage behavior, porosity and structural characteristics. A comparative analysis was conducted with conventional concrete mixtures to determine the relative improvement in environmental and performance indicators.

The results show that the incorporation of natural nano-aggregates extends the functional spectrum of traditional concrete. The modified composites demonstrate improved moisture management, increased heat storage capacity and improved absorption properties due to their highly porous internal structure. Furthermore, these materials demonstrate a reduced carbon content and potential for reuse, which contributes to cyclical construction strategies. The results of the studies show that such composites actively influence the stability of the indoor environment, reducing humidity fluctuations and improving thermal inertia. These properties contribute to the formation of housing capable of adapting to diverse urban contexts while maintaining established standards of human comfort.

In addition to material characteristics, the study addresses spatial integration strategies. Modern urban environments often suffer from excessive mineralization and limited sensory diversity. Human well-being depends on multisensory interaction with natural components, including sound, texture, lighting variations, and air quality. Therefore, a systemic transition from a purely man-made environment to ecologically enriched urban spaces is necessary. This transformation can be achieved through the structured inclusion of vertical gardening systems, acoustic absorption elements, optimized insolation design, semi-wild ecological fragments, and adaptive light-sound environments. Such measures allow urban residents to experience restorative natural interactions within technologically advanced infrastructure.

These investigations confirm that adaptive housing based on eco-modified composites and nature-integrated spatial solutions is a viable direction for sustainable urban development. The proposed approach reconciles technological progress with ecological integration and provides a scientifically sound basis for post-war reconstruction and future urban expansion, ensuring improved living comfort, adaptability, and environmental feasibility without compromising engineering performance.

Indoor CO_2 direct air capture (iCO_2-DAC): Indoor air pollutants as renewable carbon source

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Introduction and Aim: Indoor environments serve as primary shelters, yet epidemiological evidence indicates that indoor air pollutant (IAP) levels, including CO_2, are often higher than outdoors. Since individuals spend 80–90% of their time in enclosed spaces, maintaining high indoor air quality (IAQ) is a critical public health concern. While outdoor CO_2 levels are approximately 407 ppm_v, indoor concentrations typically range from 1000 to 3000 ppm_v and can peak at 6000 ppm_v due to human metabolism and inadequate ventilation. This study aims to assess the feasibility of Indoor CO_2 Direct Air Capture (iCO_2 -DAC) as a renewable carbon source. By utilizing amine-supported chemisorption to concentrate metabolic CO_2, the proposed technology simultaneously purifies indoor air and provides a feedstock for microbial electrosynthesis (MES) to produce carbon-neutral fuels.

Results: The performance of the iCO_2-DAC system was evaluated across three specific building scenarios: a high school classroom, an office, and an underground transport cabin. The simulations focused on the capture efficiency and the subsequent conversion of CO_2 into methane or ethanol to provide local heating. Results indicated that methane is the most viable product for building integration, as it requires a significantly smaller reactor footprint, of approximately 1.5 1.7 m^3 for offices and schools, compared to the much larger volumes required for ethanol. From an energy perspective, the power consumed for CO_2 desorption and conversion resulted in an estimated electricity cost of 4.1–6.1 €/d per room. While currently higher than the cost of traditional fossil fuels, this expenditure remains lower than the EU non-household average electricity cost

Conclusions: This work demonstrates that iCO_2-DAC is a promising strategy for the future of sustainable architecture and green buildings. By capturing CO_2 at the source, the technology effectively improves IAQ, mitigating health risks and cognitive degradation associated with poor ventilation. Furthermore, it promotes the circularity of resources by transforming a waste metabolic byproduct into a renewable fuel for on-site use. Although further research is needed to reduce the footprint of conversion modules and optimize costs, the integration of iCO_2-DAC with building-integrated renewable energy sources offers a viable pathway toward carbon-neutral indoor environments.

Assessment of individual human sensations in an environment with variable parameters

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Although thermal comfort in buildings is not a new topic, due to its complexity it is still widely discussed in the literature. It influences our health, well-being and productivity. The classic approach to assessing thermal comfort in rooms assumes steady–state conditions which can only be achieved in a strictly controlled environment. This state is difficult to maintain in buildings. Simultaneously, it is natural for the human body to actively respond to changes in microclimate parameters and adapt to its surroundings. This adaptation process may, but does not necessarily, imply a lack of thermal comfort or reduced productivity.

An experiment in a climate chamber was conducted where air supply settings were modified at approximately 15-minute intervals. This allowed us to investigate thermal sensations, expectations and perceived mental states of occupants exposed to an environment with dynamically changing indoor parameters. The study participants completed questionnaires every 4 minutes. In addition to subjective data, the settings of the HVAC system were recorded, and continuous measurements of microclimate parameters were conducted. These included air temperature, radiant temperature, relative humidity, air velocity, and CO_2 concentration. This combined dataset enabled analysis of the relationships among dynamic environmental conditions and participants' thermal perception as well as self-reported mental condition.

The findings contribute to a better understanding of human responses in dynamic indoor environments and may be an initial reference point to future analyses to support the development of more adaptive and user-centred climate control strategies.

A methodological review of AI-based advisory systems for HVAC management

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Artificial intelligence has been widely investigated for improving the performance and efficiency of HVAC systems. Existing reviews have extensively explored the potential of AI applications for control, optimization, energy prediction, and fault detection in HVAC systems. However, compared with the numerous studies in this area, few reviews emphasize systems that explicitly function as advisors, providing actionable feedback to human operators. As a result, it remains unclear how AI advisory systems for HVAC are implemented in practice and to what extent they extend beyond fault detection to provide operational decision support.

The aim of this study is to conduct a methodological review of AI-based advisory systems for HVAC systems, focusing on the methods used in these advisories, including the selection of AI models, the types of faults or operational issues addressed, and the different ways actionable feedback is generated.

The reviewed studies are systematically analyzed using a set of methodological criteria, including HVAC system type, building type, AI techniques employed, data sources, fault categories, and the presence and type of advisory actions. Comparisons are used to summarize design choices across studies, including whether actionable recommendations are provided, the types of actions suggested, how system performance is evaluated, and whether energy efficiency improvements are reported. This structured analysis enables identification of common implementation patterns, methodological limitations, and gaps between analytical fault detection and practical advisory support.

The analysis provides insight into how AI advisory systems for HVAC are currently implemented, highlighting the diversity of system architectures and the lack of standardization. The findings highlight key challenges related to translating AI outputs into practical operational advice, as well as the limited emphasis on human interaction and real-world deployment. By focusing on methodological practices, this review establishes a practical foundation for developing future AI advisory systems and identifies strategies to enhance their applicability and operational value.

Requirements for permissible CO_2 concentrations in indoor air in schools – worldwide examples

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Indoor air quality (IAQ) is crucial for ensuring human cognitive abilities. This is particularly important in educational buildings, such as schools, where minors – who are especially sensitive to adverse environmental conditions – spend their time. One of the proven and well-known indicators of IAQ is carbon dioxide (CO_2), whose excessively high concentration may cause problems among students, including difficulties with concentration, learning, and following teachers' instructions, as well as drowsiness, headaches, irritability and major health concerns. Since children spend most of the day in schools, it is justified to undertake activities, including the development of IAQ guidelines, that will make it possible to provide them with a healthy indoor environment.

The aim of this paper is to review selected requirements concerning the permissible CO_2 concentration levels in schools that are in force in various countries worldwide. The analysis was based on data included in the Indoor Environmental Quality Guidelines database and on a review of detailed national guidelines for each of the analysed countries. Only guidelines directly addressed to school buildings were considered. These concerned countries such as the Netherlands, Estonia, New Zealand, Denmark, the United Kingdom, South Korea, Japan, and Lithuania.

In total, 14 governmental and non-governmental guidelines across 8 countries were analysed. The review confirms that there is still a lack of uniform recommendations regarding the maximum allowable CO_2 concentration in school classrooms. The maximum allowable CO_2 level ranges in analysed regulations from 700 ppm to 1500 ppm. It can be observed that the permissible CO_2 concentration depends on the type of ventilation system used in the building. In the analysed cases, the threshold CO_2 level in naturally ventilated rooms was higher than in mechanically ventilated rooms, which is understandable due to the limited ability to control the effectiveness of natural ventilation. The analysis also revealed gaps in guidelines dedicated specifically to schools. In the Indoor Environmental Quality Guidelines database, only 8 out of 28 countries included CO_2-related guidelines targeted at educational buildings. Although general-building guidelines may also be applied, it should be remembered that children belong to a group that is particularly vulnerable to poor air quality, meaning that the development and application of CO_2 concentration guidelines tailored to their needs is essential.

Indoor air quality in kindergarten under winter conditions: Evidence from Northern Poland

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Indoor air quality in kindergartens is of particular importance because children are significantly more vulnerable to air pollution than adults. Their lungs, nervous systems, and immune systems are still developing, making them more susceptible to the adverse effects of environmental pollutants. Exposure to air contaminants such as particulate matter (PM2.5 and PM10), nitrogen dioxide (NO_2), and formaldehyde may impair physiological development and increase the risk of short- and long-term health problems. Moreover, children inhale a greater volume of air per unit of body weight compared to adults, which results in proportionally higher pollutant uptake under identical air quality conditions. Elevated concentrations of carbon dioxide (CO_2) and volatile organic compounds (VOCs) may lead to symptoms such as drowsiness, headaches, and reduced ability to concentrate.

This article presents the results of a study on the indoor environmental conditions in a kindergarten located in northern Poland. The primary objective of the research was to assess indoor air quality, with particular emphasis on carbon dioxide concentration as an indicator of ventilation effectiveness.

Due to the size of the classroom, measurements were conducted using two monitoring devices placed at distant locations within the room. Most kindergartens in Poland are not equipped with mechanical ventilation systems; instead, they typically rely on natural (gravity) ventilation supported by periodic window airing. The measurements were carried out during the winter season, with outdoor air temperatures ranging from –15.3°C to +4.7°C. This period was selected because indoor air quality often deteriorates at low outdoor temperatures as ventilation rates are reduced.

The results showed that peak carbon dioxide concentrations reached 2257 ppm, exceeding the recommended limit by more than twofold. Peak concentrations of volatile organic compounds reached 1860 ppb, which also represents a significant exceedance of World Health Organization (WHO) guideline values. The findings indicate that poor indoor air quality in kindergartens is largely associated with insufficient ventilation practices and inadequate airing habits.

Analysis of HVAC systems regarding the EU Regulation 2024/573

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The purpose of this study is to clarify and draw attention to the main changes and obligations arising from the new European Union Regulation 2024/573 and their consequences.

Nowadays heat pumps use a wide range of fluorinated gases (F-Gas) as refrigerants. In accordance with Regulation 2024/573 of the European Parliament and the Council of the European Union 2024/573 of 7 February 2024 to lower Global Warming Potential (GWP) more rapidly, in line with the EU climate targets, it will be required for industry to transition to alternative refrigerants. A new EU strategy has been launched as part of the Green Deal to reduce and eventually eliminate F-gas as working fluids in equipment commonly used in heating and cooling systems. The regulation significantly tightens previous limits and requires a very rapid reduction in the use of hydrofluorocarbons (HFCs). Between 2025 and 2035, bans on the use of refrigerants with high Global Warming Potential (GWP) will be gradually introduced in specific groups of equipment. This will mean a fundamental restructuring of the HVAC market. In some equipment groups (e.g. monoblock air source heat pumps), the transition to environmentally friendly refrigerants such as propane (R290) is a natural one. Due to EU and national regulations, the installation of equipment operating on this and other environmentally friendly refrigerants may be significantly hampered. This poses a challenge for manufacturers to develop technical solutions that will enable the use of equipment in accordance with regulations or the introduction of new refrigerants to the market.

The aim of this work is to review current solutions in light of applicable regulations and to attempt to identify possible directions for market development based on existing technical solutions.

The study adopted a methodology based on the verification of currently implemented solutions. Through an analysis of technical documentation provided by leading heat pump manufacturers available in European, combined with an empirical evaluation of the applied solutions, a comparative analysis was conducted to determine whether these solutions satisfy the requirements of European regulations, particularly in the areas of safety and environmental protection.

Hybrid ventilated façade with integrated energy converter: Experimental approach to energy-efficient building envelopes

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The transition toward low-carbon, energy-efficient, and climate-resilient buildings requires façade systems capable of reducing heat losses, integrating renewable energy, and improving indoor comfort. Conventional ventilated façades, although effective for moisture control and durability, still generate thermal bridges and allow low-grade heat to escape through the ventilated cavity. To address these limitations, the R&D project POIR.01.01.01001188/18, cofinanced by the European Union under the European Regional Development Fund, developed and tested a Hybrid System of Ventilated Façade with an Integrated Energy Converter (HSEWPE) on a prototype wall sample. The aim of the research was to develop, model, and validate a façade technology that uses solar energy and supports HVAC systems in both new and retrofitted buildings, while also enabling renewableenergy generation through façadeintegrated photovoltaic elements.

The system comprises a multifunctional cladding layer, a lightweight subframe, a ventilated cavity with an integrated energy converter, and an external wall designed to support energy-assisted HVAC operation. It was tested on an approximately 18 m² sample of ventilated external wall. The hybrid façade system, consisting of nine PV panels measuring 1730 × 1133 × 30 mm, achieved an output of 1395 W when operated with the cooling system and 1349 W without cooling. This corresponds to a power output of 79.08 W/m² of façade surface for the cooled configuration and 76.47 W/m² for the configuration without cooling. The results indicate that the cooling system is capable of providing an additional 2.6 W/m² of ventilated façade surface.

The results confirm that HSEWPE significantly enhances building energy performance by reducing heat losses and recovering renewable low-grade energy. The integration of vertically mounted PV panels expands the renewable-energy potential of building envelopes, even where roof installation is constrained. The system may also contribute to HVAC performance by providing a more thermally stable boundary condition for heat pump operation, particularly during transitional seasons. Overall, the hybrid façade system represents a technically feasible approach to improving the energy performance of building envelopes and supporting low-carbon solutions.

Environmental comfort in visitor-centre spaces: A qualitative contribution to indoor environmental quality research

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Tourism increasingly unfolds within diverse built and semi-built environments, including hybrid indoor–outdoor visitor centres. In these contexts, indoor environmental quality (IEQ), including thermal conditions, ventilation, lighting, and acoustics plays a significant role in shaping visitors' embodied experience of space. In building science, comfort is typically defined in relation to measurable environmental parameters such as temperature stability, air quality, and acoustic performance. In this study, comfort refers specifically to environmental comfort, understood as the regulation of thermal, ventilation, lighting, and acoustic conditions within enclosed or semi-enclosed tourism spaces. These environmental factors are examined not only in terms of physical regulation but also in relation to their contribution to visitors' perceived comfort and ability to remain thermally and cognitively stable within the space.

This research-in-progress investigates how environmental comfort is experienced within visitor centres, including cultural and natural tourism sites in Catalonia such as the interpretive facilities at Montserrat. These environments are mechanically or passively regulated to support artefact preservation, visitor circulation, and energy efficiency. They typically involve controlled thermal settings, managed ventilation systems, artificial or filtered natural lighting, and acoustic modulation. The study focuses on how visitors perceive temperature stability, air freshness and ventilation adequacy, lighting quality, acoustic balance, material surfaces, and spatial organisation within these indoor settings.

The research adopts a qualitative design based on in-depth, semi-structured interviews with individuals reflecting on recent experiences in the visitor-centre spaces in Montserrat. Rather than assessing technical parameters directly, participants describe sensations of warmth or coolness, perceived air movement and freshness, brightness or glare, reverberation or noise, and overall physical ease. They also reflect on how these environmental conditions influence attentional engagement and mental comfort while navigating cultural displays.

Preliminary findings indicate that environmental comfort in tourism spaces is experienced as dynamic rather than fixed. While thermal stability and adequate ventilation are fundamental, comfort evaluations are shaped by expectations, duration of stay, mobility patterns, and cognitive demands. Environmental stability supports both bodily regulation and sustained attention, whereas overheating, insufficient ventilation, or acoustic disturbance may disrupt concentration and diminish experiential quality.

By integrating qualitative user perspectives into IEQ research, the study contributes to discussions on human-centered thermal comfort and energy-efficient design in cultural buildings. The findings highlight how decarbonization strategies must balance technical performance with visitors' lived experience of environmental comfort.

Assessment of primary energy demand for selected heat sources in a reference multi-family residential building across different climate zones of Poland

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In light of the ongoing energy transition in the building sector and the increasingly stringent legal requirements concerning the energy performance of buildings, the analysis of the efficiency of various heat supply systems in terms of primary energy (PE) is gaining particular importance. The PE index constitutes one of the key criteria for energy assessment, reflecting not only system efficiency but also the environmental impact of the energy source used. Considering the energy structure of Poland, characterised by a high non-renewable primary energy factor for electricity, the selection of an optimal heat source becomes a multidimensional process requiring consideration of both technological diversity and climatic conditions.

The aim of this study was to estimate and compare the primary energy index (PE) of selected heat sources, including: a gas boiler, a gas boiler supported by solar collectors (hybrid system), air-source and ground-source heat pumps and their configurations with a photovoltaic system, a coal-fired boiler, and a district heating substation, for a representative multi-family residential building. The analysis was carried out using specialised software Audytor OZC 7.0, which enables the modelling of energy demand and the assessment of the efficiency of building technical systems, in accordance with the current methodology for issuing energy performance certificates. The study was conducted for five locations across Poland – Gdansk, Wroclaw, Warsaw, Bialystok and Zakopane – representing different climate zones.

The analysis revealed significant variations in the values of the PE index depending on the applied heat source and the building location. The results confirmed the high potential of systems based on heat pumps, particularly when combined with photovoltaic installations, as well as district heating substations supplied by cogeneration-based systems. At the same time, the limited competitiveness of traditional fossil fuel-based solutions in the context of current energy performance requirements was demonstrated. It was also concluded that the appropriate selection of a heat source, taking into account both climatic conditions and the possibility of integration with renewable energy sources, constitutes a key element in strategies aimed at improving the energy efficiency of buildings.

Indoor air quality and ventilation strategies in crowded classrooms: Evidence from a field study in Ferrara

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Indoor air quality (IAQ) plays a crucial role in both the physical and psychological well-being of occupants, particularly in densely occupied environments. Inadequate ventilation can result in the accumulation of pollutants and decreased comfort, potentially leading to symptoms linked to Sick Building Syndrome (SBS).

The SYMBIEN (Schools Symbiotic Environments) research project, carried out at Liceo Ariosto in Ferrara within a student orientation initiative, involves the Universities of Ferrara and Bologna in collaboration with the Municipality and Province of Ferrara. The study examines indoor air quality in a classroom setting by comparing natural ventilation with a mechanical ventilation system equipped with heat recovery (MVHR).

Extensive long-term monitoring was performed, including measurements of temperature, relative humidity (RH), carbon dioxide (CO_2), radon, volatile organic compounds (VOCs), particulate matter (PM2.5), as well as lighting levels, electricity use, and heating demand. In addition, microbiological tests on both air and surfaces (such as desks and floors) were carried out before and after classes. Green walls were also introduced to evaluate the contribution of vegetation to indoor environmental quality.

The preliminary findings presented here emphasize the limitations of relying solely on natural ventilation in crowded indoor spaces.

Importance of thermal bridges in wooden platform framing constructions

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Wooden platform framing structures have been the predominant construction typology for residential buildings in North America for more than half a century, providing ample time to optimize the system in terms of energy efficiency, construction duration, and cost-effectiveness. In addition to these qualities, favourable seismic performance and structural flexibility have contributed to the increasing adoption of this building technique in other regions of the world, including Turkey, Japan, and the European Union. Owing to the ease of assembly, wooden platform framing is particularly well suited for prefabrication and can therefore be effectively employed in small to medium-scale collective housing developments.

Wood exhibits significantly lower thermal conductivity than concrete or metal; consequently, the issue of linear thermal bridges in wooden structures is often underestimated. This has resulted in limited research on the topic and a prevailing practice in which thermal bridging effects are frequently left unexamined.

The aim of this research is to analyse, through computer-based modelling, the various linear thermal bridges characteristic of wooden platform framing structures. These include external wall intersections, intersections between external and internal walls, wall-to-slab connections, wall-to-intermediate slab connections, and wall-to-roof intersections, examined across multiple configurations. The results are presented in a clear and comprehensive tabular format. This research forms part of a broader initiative aimed at developing a guideline for architects and engineers to support the evaluation and design of Nearly Zero Energy Buildings.

Adaptive façades: A review and a proposal for the classification of the existing solutions

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Currently, the building and construction sector represents one of the major contributors to global environmental impact, accounting for approximately 34% of global CO_2 emissions. Within this context, the building envelope has progressively evolved from a traditional static barrier into a strategic and dynamic interface between indoor and outdoor environments. Adaptive facades have consequently emerged as a promising technological solution to enhance energy efficiency and occupants' comfort, through the reversible modification of their physical and performance characteristics in response to changing climate conditions and user needs.

Although their potential is widely recognized, adaptive façades are still difficult to adopt on a large scale. Most of the current applications are based on engineer-to-order design processes, leading to tailor-made solutions developed specifically for each specific context. This absence of standardization not only limits large-scale adoption but also contributes to a fragmented body of knowledge. In the current literature, a noticeable conceptual fragmentation makes it difficult to systematically describe, classify, and compare solutions.

This research aims to address these gaps by presenting an early critical review of the scientific literature and a classification of adaptive facades developed by the authors. The latter is conceived as a first attempt to systematize the diverse approaches proposed in the field. In fact, adaptive façades are often addressed through heterogeneous theoretical, that makes it difficult to systematically describe, classify, and compare solutions.

The study highlights recurring classification criteria, revealing at the same time the limitations of current approaches. Based on this analysis, an original theoretical classification framework is proposed. This is structured upon six main criteria: the performance objective to be achieved, the activation event triggering the adaptive behavior, the type of response implemented by the system, the response time and modality, and the level of adaptation, distinguishing between material-level adaptation and component- or system-level adaptation.

The literature review provides a reliable knowledge base for future research development related to the topic of adaptive façades. Furthermore, the classification outlined during the study could represent a solid methodological background for more detailed analyses, highlighting at the same time the considerable potential and advantages of similar technological solutions.

Building energy audit, thermal comfort, and costs assessment of two school buildings: A case study

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This paper presents a detailed case study on the comprehensive thermal rehabilitation of two kindergarten buildings located in Beiuș, Romania. Thermal refurbishment of existing educational buildings plays a key role in reducing energy consumption, operational costs, and environmental impact, particularly in the context of European climate and energy policies. In Romania, such interventions are partially financed through European Union funds, provided that the projects comply with legally defined requirements regarding thermal protection and energy performance.

The study evaluates the thermal modernization of the two buildings in accordance with current Romanian regulations and technical guidelines. A thorough assessment of the existing buildings is carried out, including the characterization of the building envelope, thermal resistances, HVAC systems, and local climatic conditions. Based on this assessment, a set of rehabilitation measures is proposed, targeting improved energy efficiency and reduced greenhouse gas emissions. The expected performance improvements are quantified using the primary energy consumption indicator and associated CO_2 emissions.

After the implementation of the rehabilitation measures, a real cost analysis was conducted, revealing an investment cost of 3345.3 Lei/m², equivalent to 655.95 Euro/m². In addition, the simple payback time (SPBT) of the applied measures is determined to assess their economic viability. The annual calculated heating energy consumption was reduced from 330.9 kWh/m² and 321.3 kWh/m² to 104.8 kWh/m² and 101.6 kWh/m², respectively. At the same time, annual CO_2 emissions decreased from 27 tons to 11.65 tons.

The results demonstrate that deep thermal rehabilitation of educational buildings can lead to substantial reductions in energy demand and carbon emissions, while remaining economically feasible when supported by public funding mechanisms. The findings contribute to the growing body of evidence supporting large-scale energy renovation strategies for public buildings in Eastern European contexts.

Determination of building heat demand based on actual heat consumption

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Multi-family buildings in Polish cities are usually supplied with heat by District Heating Companies. The basic elements of the cost of heat consist of two components: the first is the fee for the contracted capacity, and the second is the payment for the heat consumed. Currently, most buildings have undergone thermal renovation, usually involving insulation of external partitions and replacement of windows and doors with new ones that offer better airtightness and lower thermal transmittance. Buildings after thermal renovation have lower heat demand. Therefore, the contracted capacity (the maximum heat demand) ordered from the supplier should be adjusted.

This capacity can be determined in two ways: the first is based on calculations, and the second is based on the amount of heat consumed for heating the building. In the first method, it is determined based on the geometry and construction of the building as well as the thermal parameters of the building envelope components. It is also necessary to assume data regarding the outdoor temperature and the indoor temperatures within the building.

In the second method, to determine heat consumption, data obtained from heat meters installed in buildings and outdoor temperature values for individual days are used.

This paper presents a method for determining the design heat demand corresponding to the contracted heat capacity based on heat consumption. Based on readings from heat meters, the amount of heat consumed for heating is determined over several or a dozen heating periods (e.g., monthly periods during the heating season). After determining the average daily heat consumption and the average daily outdoor temperature for the analyzed periods, regression analysis is used to determine the parameters characterizing the correlation between the daily heat demand for heating the building and the outdoor temperature.

Knowing the parameters of the function describing heat demand as a function of outdoor temperature, the heat demand for the design outdoor temperature (heat load) is calculated. An example of this determination is attached to the paper.

Analysis of room temperature decrease as a result of an interruption in the heat supply

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The issues related to thermal comfort in rooms are important in the context of unplanned interruptions in thermal energy. This problem is considered in the context of energy security, which is considered in the operation and use of buildings. The configuration of the building envelope structures has a significant impact on the level of thermal safety.

The authors of the article conducted experimental studies on the thermal functioning of rooms located in different zones of buildings with different external wall solutions. The article presents the results of the research conducted. A relationship was observed between the thermal capacity of the envelopes and the rate of air temperature drop in rooms where a planned interruption in the supply of thermal energy occurred.

The results are presented in graphic form. Research conducted indicates that the structure of the building envelope significantly influences the rate of temperature drop in rooms during interruptions in the supply of thermal energy during the heating season. Research allows the formulation of recommendations for the design of buildings to ensure comfort of use in the context of operational safety.

Theoretical analysis of ETICS performance in cold and humid climates based on experimental hygrothermal characterization

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The growing popularity of ETICS systems is strongly influenced by the European Union's efforts to improve energy efficiency and expand building renovation programs. In 2020, during the peak of the COVID19 pandemic, the European Commission introduced two significant initiatives: the "Renovation Wave" and "NextGenerationEU." However, the use of ETICS always faces environmental challenges, such as adaptation to climate zones, wear and tear of external envelopes, compatibility of various new materials, conflict between thermal and moisture properties, and planning service life during the life cycle.

This article examines ETICS with a painted thin render and insulated with mineral wool slabs from the outside, as defects caused by the condensed moisture accumulated in the envelopes become more and more frequent. Water vapour permeability of the exterior finish (i.e. the paint), if compared with the water vapour permeability of the mineral wool slab, is rather small. That is why the paint coating may become a barrier for water vapour diffusion and thus create favourable conditions for moisture accumulation in the exterior layers of the envelope during cold seasons. As a rule, to eliminate such defects, the exterior surface is repainted on the preserved former paint coating because the render is thin and mechanically easily damaged. The repainting of the thin render surface causes the following: 1) increase of the exterior coating's vapour resistance; 2) growth of the condensation intensity in the envelopes' exterior layers during the period of moisture accumulation; 3) decrease of the durability of the render-paint system.

The European Union has approved standards that impose strict restrictions on the s_d values of the outer layer of the cladding, which are <1.0 m. However, moisture accumulation inside the wall depends on the local climate, so it is important to determine whether the recommendations for the specified s_d value can be applied to the outer layers of Lithuanian building walls. To find this out, calculations of the condition of the cladding and laboratory experiments were carried out. The aim of this article is to analyze the effect of vapor permeability and its properties in the outer layers of the wall on the moisture condition of the cladding. It was found that the increase in s_d values is disproportionate to the number of paint layers or the thickness of the paint coating. It was also found that the increase in s_d values creates conditions for increased moisture content under operating conditions, caused by water diffusion and condensation. Experiments have shown that, under Lithuanian climatic conditions, the s_d value of the thin outer layer of plaster on the walls of buildings in service should be s_d<0.5 m, and that of the paint coating should be s_d<0.6 m. The results obtained show that the s_d values given in the EU standards are too lenient for ETIC systems in buildings located in cold climate zones of the EU, and this does not ensure their long-term use.

Analysis of thermophysical parameters of the external wall–foundation slab junction in buildings

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The junction between the external wall and the foundation slab is one of the most critical areas of the building envelope in heated buildings. As an interface between various materials and structural solutions, it has a decisive impact on the magnitude of heat loss and the temperature distribution in the ground-contact zone. Improper configuration of the thermal insulation parameters of this detail leads to the intensification of thermal bridges, manifested by an increase in the linear thermal transmittance (ψ-value) and a decrease in the internal surface temperature at the critical point of the junction.

The aim of the research was to analyze the thermophysical parameters of the junction by determining the degree of influence of selected insulation factors on its thermal characteristics. The study analyzed five variables determining the energy efficiency of the connection:

- thickness of the thermal insulation of the slab-on-ground [m],
- thickness of the thermal insulation of the plinth area [m],
- thickness of the external wall thermal insulation [m],
- thermal conductivity coefficient λ of the plinth insulation [W/(m·K)],
- thermal conductivity coefficient λ of the slab-on-ground insulation [W/(m·K)].

The analysis was conducted using two-dimensional numerical heat-transfer modelling. To streamline the computational procedure, a five-factor, three-level fractional factorial design was applied, resulting in an experimental matrix of 27 simulation cases. The study was performed for the climatic conditions of Białystok, adopting assumptions appropriate for ground freezing zone II (depth of 1.2 m) and a design outdoor temperature of t_e = -22°C. For each case, the temperature at the junction's critical point and the *ψ-value* corresponding to the specific insulation solutions were determined. The calculation results allowed for the identification of factors exhibiting the strongest influence on the thermal parameters of the connection, as well as the determination of the direction and intensity of this impact. The proposed approach enables the selection of rational insulation parameters that effectively limit energy losses and ensure the hygrothermal safety of the structure.

Digital 3D visualization of laboratory spaces for enhancing education and safety

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Introduction and aim of the research: The increasing complexity of laboratory-based education in engineering, construction, and medical sciences requires the application of innovative approaches to spatial orientation, safety preparation, and interdisciplinary learning. Traditional forms of laboratory training often expose students to unfamiliar working environments without prior spatial and procedural familiarization, which may lead to operational difficulties and safety-related risks. The aim of this research is to present an applied framework for the use of immersive 3D visualization of laboratory spaces as a preparatory tool for students prior to their physical entry into laboratories, using a real university laboratory as a case study.

A high-resolution 3D spatial model of the laboratory environment was developed, enabling virtual access to the space before physical entry. The virtual environment supports interactive navigation, identification of laboratory equipment, visualization of functional zones, and guidance of movement paths through spatial annotations and descriptive metadata. The results indicate that immersive 3D visualization improves students' initial spatial understanding, facilitates early familiarization with laboratory procedures, and reduces safety-related uncertainties during first-time physical access to laboratory environments. In addition, the developed model provides structured digital documentation of laboratory spaces, supporting infrastructure analysis and future planning activities.

The study confirms that immersive 3D visualization of laboratory spaces represents an effective interdisciplinary tool for pre-laboratory student preparation. Beyond its educational benefits, the proposed approach contributes to safer use of laboratory infrastructure and supports the sustainable digital transformation of educational institutions. The methodology is adaptable across multiple disciplines, including engineering, construction, and medical education, and provides a foundation for integration with digital twin and smart infrastructure concepts.

Keywords: immersive 3D visualization, laboratory education, interdisciplinary learning, digital infrastructure, smart laboratories

UV germicidal irradiation installations – reliability versus energy efficiency

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Introduction

The COVID19 pandemic highlighted the essential role of microbial safety and stimulated intensified research in this field. In indoor environments, pathogenic microorganisms can be transmitted both through the air and via contaminated surfaces; therefore, a variety of disinfection strategies may be employed. Among these, ultraviolet germicidal irradiation (UVGI) systems based on lowpressure mercury (LP Hg) lamps remain widely used. However, due to the harmfulness of the emitted radiation, such systems cannot operate without shielding in the presence of humans. A significant contemporary research direction focuses on the development of UV sources that emit within spectral ranges considered safe for direct human exposure while remaining effective for surface decontamination. The emergence of such technologies is expected to enable broader application of UV-based disinfection in occupied spaces. In this context, the optimization of UVGI systems is increasingly relevant due to their implications for energy consumption and building performance assessment. Despite this growing importance, standardized design procedures and performance criteria remain limited. This study aims to address this gap by evaluating the potential for optimizing UVGI systems with respect to their disinfection performance and energy efficiency.

Simulations were performed in a case study interior by calculating the irradiance distribution provided by 66 versions of the UVGI system with LP Hg lamps. Further, the analysis was performed by adopting a standard procedure to evaluate energy efficiency of lighting installation. The results calculated for a hypothetic disinfection schedule revealed a significant dispersion of energy consumption of the system. In the analyzed case study interior, the average value was 13,92 kWh/(m^2·year) with minimum of 6,22 kWh/(m^2·year) and maximum of 21,39 kWh/(m^2·year). The values increase when the modification of the evaluation procedure is introduced in order to assure the disinfection reliability. Further, factors affecting energy consumption for surface disinfection are identified and analyzed.

The conducted research indicates the need and feasibility of developing procedures and criteria for the sustainable design of surface disinfection systems. The methodology used enables the assessment of the energy efficiency of UVGI systems.

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Changes in radiative exchange in gaps in ETICS systems

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Increasing thermal performance requirements for buildings necessitate the development of modern solutions that enhance envelope efficiency and reduce energy demand. One underexplored aspect of building thermal physics is radiative heat transfer within air cavities occurring at interfaces in ETICS (External Thermal Insulation Composite System) assemblies, particularly between concrete structural layers and thermal insulation. Such gaps may substantially affect overall heat transfer, as radiation can dominate under typical operating temperatures. The aim of this study was to improve the thermal resistance of air cavities in ETICS systems by modifying the surface emissivity of concrete substrates through the application of reflective–smoothing coatings. The research was interdisciplinary in nature, combining emissivity measurements, three-dimensional surface topography analysis, and numerical modelling of heat transfer. Surface emissivity in the 7–12 μm infrared range was measured using thermography under controlled laboratory conditions. Surface morphology before and after coating application was examined using 3D optical scanning, reverse engineering tools, and dedicated topography analysis software. In total, seven commercially available coatings were analyzed.

The results confirmed that the application of coatings significantly influences surface emissivity, with reductions ranging from approximately 1% to as much as 70%, depending on the product used. Uncoated concrete exhibited high emissivity (≈0.95), while the most effective coating (acrylic enamel) reduced emissivity to approximately 0.29. Aluminum spray also produced a noticeable reduction, whereas thermally insulating paint showed only minor impact. A clear correlation was identified between emissivity reduction and surface leveling: smoothing of micro-scale irregularities and changes in micro-facet geometry contributed to limiting radiative exchange. The experimentally obtained surface geometries were implemented in a validated CFD-based numerical model to simulate heat transfer across a 20 mm vertical air gap. Reducing emissivity from 0.95 to 0.29 increased the air-gap thermal resistance from 0.189 to 0.311 m^2K/W, leading to a measurable decrease in the overall U-value of the wall assembly.

The study demonstrates that modifying surface emissivity has a direct and significant impact on heat transfer within air cavities in multilayer wall systems. Controlling radiative exchange through reflective–smoothing coatings represents a practical and potentially implementable strategy for improving building envelope performance without increasing wall thickness. The findings highlight the importance of incorporating radiative mechanisms and surface topography effects into advanced thermal analyses. Further research in this direction offers strong application potential, supporting the development of energy-efficient and low-emission building solutions.

Geometric compactness and the surface to volume ratio: A review of recent advancements in passive decarbonization

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The global building sector accounts for nearly 40% of energy consumption and remains a primary contributor to greenhouse gas emissions. As the European Union transitions toward the 2024/2026 Energy Performance of Buildings Directive (EPBD), focus has shifted from active mechanical systems to passive architectural strategies. Among these, the surface to volume (S/V) ratio is the most critical determinant of energy demand. Despite the thermal advantages of compact forms, contemporary architecture frequently prioritizes fragmented geometries that increase envelope exposure. This "thermal leakage" creates a significant barrier to achieving Net-Zero Emission Building (NZEB) status, particularly in cold-temperate climates like North-Eastern Poland.

This paper provides a comprehensive overview of studies published between 2023 and 2026. By synthesizing data from parametric modeling, spatial econometric analysis, and life cycle assessments, the research evaluates shape-driven energy efficiency. It specifically quantifies the energy penalty of geometric complexity and identifies the optimal compactness required to balance thermal retention with natural lighting and comfort.

Recent literature reveals a non-linear correlation between building morphology and energy intensity. Spatial econometric analyses by Zhou et al. (2025) demonstrate that a 10% increase in geometric fragmentation can trigger a 15% to 22% surge in heating demand within high-latitude regions. Complementary research suggests that while absolute compactness minimizes heat loss, the "optimal" form for cold climates often involves strategic "unfolding" to maximize winter solar gain; this can improve passive performance by up to 12% without significantly increasing the S/V ratio. Furthermore, investigations into high-rise clusters suggest that the aspect ratio is the most significant factor influencing Energy Use Intensity (EUI), with optimized layouts yielding reductions of approximately 7.73%. These findings are compounded by life-cycle perspectives from the Structural Science Group (2023), which indicate that high S/V ratios necessitate 25-30% more insulation and cladding per square meter. Thus, geometric complexity creates a dual burden: increasing annual operational demand while inflating the initial embodied carbon footprint.

The review concludes that geometric compactness remains the most cost-effective passive strategy for decarbonization. While HVAC and PV innovations are vital, they cannot fully compensate for the energy losses inherent in inefficient building forms.

The impact of thermal bridge solutions on usable energy in a single-family building

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Given the growing demands for energy efficiency and the need to reduce energy consumption in the construction sector, the quality of designing building envelopes and their connections is becoming particularly important.

Contemporary newly designed buildings are subject to increasingly stringent legal and standard regulations, leading to a significant reduction in usable energy demand. However, meeting global requirements does not guarantee optimal thermal performance at the individual level.

In design practice, thermal insulation disruptions, known as thermal bridges, play a significant role in energy efficiency. Thermal bridge design solutions can be implemented in an energy-inefficient manner (without analysis), often resulting in increased heat loss, or optimized to reduce excessive heat flow. Therefore, the analysis and proper optimization of thermal bridges is a key element in the design process of energy-efficient buildings.

The aim of this research is to determine the impact of structural detail solutions on the level of usable energy consumption in single-family buildings. The results of the analyses indicate a difference of up to 10-15%. The conclusions from the analyses indicate the need to introduce a numerical analysis stage of construction details into the design process.

B. RENEWABLE ENERGY INTEGRATION & SMART SYSTEMS

Energy and exergy performance of PEM type fuel cell – experimental study

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Growing societal awareness of the greenhouse effect and greenhouse gas emissions is driving increased interest in achieving climate neutrality. The European Union aims to reach this goal by 2050, which requires the gradual replacement of non-renewable energy sources with low-emission technologies. While large enterprises have substantial financial resources to implement advanced energy solutions, residential buildings – particularly single-family homes – are characterized by limited investment capabilities. One potential solution in this area is proton exchange membrane (PEM) fuel cells. The objective of this study was to analyze the energy and exergy efficiency of a PEM fuel cell intended for use in single-family homes, with particular emphasis on the impact of cooling water flow rate on its operational parameters. The research was conducted on a real-world prototype as part of a thesis project. The analyzed fuel cell was powered by natural gas and featured a thermal power of 1,1 kW and an electrical power of 0,75 kW. Three measurement series were performed, differing in cooling water flow rates of 0,86 l/min, 1,62 l/min, and 2,61 l/min, respectively, with each series lasting 7 days. Based on measurements of cooling water temperature, natural gas consumption, electricity production, and outdoor air temperature, the average daily energy efficiency, non-renewable primary energy input coefficient, and average daily exergy efficiency were determined, along with an uncertainty analysis using the total differential method. The results showed that the average daily energy efficiency was 68%, 87,5%, and 93,6%, respectively, with non-renewable primary energy input coefficients of 0,64, 0,42, and 0,35. The average daily exergy efficiency reached values of 30,1%, 30,3%, and 31,1%. The obtained results indicate that increasing the cooling water flow rate improves both the energy and exergy efficiency of the PEM fuel cell, confirming its viability as an effective source of heat and electricity in single-family homes, in line with energy transition goals and efforts to reduce greenhouse gas emissions.

Energy–exergy and techno-economic assessment of a solar thermal power plant under Rajasthan climatic conditions, India

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Concentrating Solar Thermal Power (CSP) plants use mirrors to focus sunlight and generate steam for electricity generation. The Parabolic Trough Collector (PTC) design is the most commercially proven CSP technology, but its solar field must be sized to local radiation. This paper presents an energy, exergy, environmental and economic analysis of proposed 50 MW PTC plants sited at ten locations in Rajasthan, India. Using satellite-derived Direct Normal Irradiance (DNI) data and Therminol® VP-1 as the Heat Transfer Fluid (HTF), plant performance for each month in each city is computed. For each scenario, the optimum HTF mass flow rate and the number of collector loops needed to achieve the design-point boiler inlet temperature is determined. The coupled Rankine Cycle is then simulated to find the monthly Net Power Output. An overall plant efficiency of approximately 37.61% is found. A second-law analysis yields component exergy efficiencies. Finally, the lifecycle CO_2 emissions caused by the plant and CO_2 avoided by displacing coal/oil generation is estimated. The results indicate that such plants would be technically feasible and environmentally beneficial at these sites, suggesting viable CSP deployment in Rajasthan's desert region.

Innovative energy efficiency, cyber-physical, and digital technologies for soil and crop quality monitoring

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The article presents innovative energy-efficient, cyber-physical and digital technologies for monitoring soil and crop quality, as well as for developing information advisory systems using artificial intelligence and optimization procedures to support decision-making in managing work processes and systems in precision agriculture. The goal is to build a multifunctional web-based platform for Bulgarian farmers. The platform offers innovative products and services that will help farmers sustainably manage their farms over time. The offered products and services are constantly updated based on ongoing interaction with farmers and the research group. The offered services focus mainly on digital analysis of soils according to their basic physical, chemical and biological properties, monitoring the quality of agricultural production, and others. The innovative approach to building innovative technologies and the platform allows for real-time exchange of information and feedback between farmers and scientists. Farmers will become not only consumers, but also participants in the research conducted for them. By supporting decisions in the management of agricultural practices, a multifunctional web-based platform helps Bulgarian farmers to implement good agricultural practices and achieve high-quality agricultural production. The article also presents a study of the energy efficiency of a wireless sensor network for measuring the main physicochemical parameters of the soil. The main physicochemical parameters of the soil - acidity and electrical conductivity - are measured. A microprocessor system has been developed for measuring the main physicochemical parameters of the soil. Based on reference measurements of nitrogen, phosphorus and potassium, models have been developed for their quantitative determination through the values of soil moisture, acidity and electrical conductivity. The study on the transmission of measured data for the main soil parameters was conducted through simulation, with program modules developed in the MATLAB environment. The study of the energy efficiency of a wireless sensor network was done in terms of the number of nodes and the distance between them, as well as the energy consumed and spent by the nodes. The research shows that the distance at which information needs to be transmitted between the sensors does not have a significant impact on the energy consumed when transmitting or receiving data between them. Additional experiments are to be conducted to establish the accuracy of measuring the parameters and to study the applicability of the development in real conditions.

Sustainability and innovation of modern vertical-axis wind turbine composite blades

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The sustainability of modern human civilization is significantly concerned with enhancing sustainable energy resources. Wind energy is regarded as one of the most promising and rapidly growing renewable energy technologies. Among wind turbine configurations, Vertical-Axis Wind Turbines (VAWTs) have grown in popularity as sustainable energy solutions. However, the primary challenge with VAWTs is complicated structural dynamics, sustainable performance, and incorporation of the optimal composite blade configuration. In this context, this study seeks to lead the global scientific committee's efforts to highlight the significant role of the dynamic approach in strengthening the sustainability and innovation of modern Vertical-Axis Wind Turbines' performance as well as shaping the prime cornerstone to achieve sustainable VAWT performance. In addition, this study presents an integrated study of the dynamic performance and fatigue-life characteristics of novel VAWT composite blade configurations. The novelty and sustainability pillars of this study can be drawn in terms of novel VAWT design optimization strategy, composite blade configurations, performance sustainability enhancement and assessment, and research methodology integration. A novel VAWT design optimization strategy using the Taguchi technique combined with the Response Surface Methodology (RSM) is employed to model, propose, and elect the optimal VAWT composite blade configurations using the Minitab statistical software package. Modified mechanical parameters were introduced to improve the sustainability, scalability, and accuracy of the developed models. Finite Element Analyses (FEAs) were conducted within the SolidWorks Simulation software to model, visualize, simulate, and predict the dynamic performance and fatigue-life characteristics of VAWT composite blades. An experimental testing program was arranged to characterize the modal parameters and fatigue-life characteristics of the fabricated VAWT composite blade configurations. Finally, a verification test and a credibility analysis were conducted to culminate this innovative research strategy and enhance its credibility. The study findings highlight the significant impact of VAWT composite blades in enhancing the dynamic performance and fatigue-life characteristics of VAWTs. Furthermore, a small damage percentage characterized by the FEA for the optimal VAWT composite blade configuration validated the sustainability of the modern VAWT composite blades in dynamic loading conditions.

Digital twin-based control for dual-axis solar trackers in autonomous energy systems

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Decentralized energy generation is critical for autonomous industrial applications, such as mobile polymer waste processing units, where power supply continuity is mandatory. Traditional static photovoltaic (PV) systems often fail to meet dynamic load requirements due to the stochastic nature of solar radiation. Consequently, existing autonomous solutions frequently suffer from energy deficits, forcing operators to rely on costly and polluting backup fossil-fuel generators. The primary problem addressed in this study is the discrepancy between the theoretical and actual energy yield of autonomous PV systems under variable environmental conditions. The aim is to develop and validate a control strategy for a dual-axis solar tracker that integrates a Cyber-Physical System (CPS) and Digital Twin technology to maximize energy harvesting and ensure operational reliability.

The study presents a high-efficiency autonomous power supply system based on a dual-axis tracking mechanism managed by a distributed microcontroller network. The control logic employs a hybrid algorithm, fusing deterministic astronomical calculations with real-time feedback from optical sensors. This approach prioritizes astronomical data during cloudy intervals to prevent erratic movements and switches to optical feedback during clear conditions for precision alignment of the PV modules relative to the sun vector. A key innovation is the implementation of a Digital Twin – a virtual replica operating in parallel with the physical tracker. By continuously comparing real-time telemetry (motor current, angular coordinates) with the reference model, the system detects anomalies such as mechanical backlash or sensor drift before critical failure occurs. Experimental validation confirmed that this CPS-based tracker increases daily energy generation by approximately 35–40% compared to fixed-tilt systems. Furthermore, the integration with a battery storage system ensures stable operation of the technological process, significantly extending the system's autonomy duration without grid connection.

Integrating Digital Twin technology into solar tracker control loops transforms them into smart, self-diagnosing assets. The proposed system significantly outperforms traditional solutions in energy yield and reliability. Optimized energy harvesting allows for reduced battery capacity, thereby lowering initial capital expenditure. The "Digital Twin" approach enables predictive maintenance and reduces the Life Cycle Cost (LCC) of the infrastructure, contributing to the development of smart microgrids**, resilient urban infrastructure, and global decarbonization goals.

Integration of renewable energy sources in urban tissue

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The dynamic development of small-scale renewable energy technologies in cities has become a principal element of the energy transition. Photovoltaic installations, heat pumps and other renewable energy technologies are increasingly implemented within existing urban structures, most often at the scale of individual buildings.

Although these solutions contribute to reducing greenhouse gas emissions and improving energy efficiency, their rapid and frequently uncoordinated deployment generates new spatial and visual challenges, particularly in dense urban environments where space is finite and architectural coherence is essential. As a result, renewable energy technologies increasingly influence the visual character of buildings and public spaces.managing the urban landscape to be visible.

Most renewable energy technologies are techno-economically viable. In many cases, small-scale renewable energy installations are introduced in an instant manner, without sufficient consideration of spatial context or their impact on architectural appearance and public space. This leads to conflicts between technical requirements and the visual quality of the urban environment.

Examples include photovoltaic panels mounted on balconies or facades, as well as external units of heat pumps located in visually exposed and representative domains of buildings. Such circumstances indicate the necessity of treating renewable energy technologies not only as technical infrastructure, but also as elements that actively shape urban space. The lack of clear spatial and design guidelines additionally intensifies these conflicts, particularly in existing urban tissue.

The aim of the work is to identify and discuss spatial and visual challenges related to the integration of small-scale renewable energy technologies in the urban environment, and to indicate possible directions for their more coherent and context-sensitive incorporation into existing buildings. The methodology combines spatial analysis with an assessment of architectural composition and building form. The study adopts a qualitative review and conceptual approach, supported by comparative spatial analysis of selected case examples documented through field observations and visual assessment. The analysed cases were selected based on their visibility within urban space and the occurrence of spatial or compositional conflicts.

According to the analysis of problematically integrated renewable energy technology samples, alternative approaches to their localisation in sensitive urban areas are introduced. These include prioritising roof surfaces, applying building-integrated photovoltaic solutions (BIPV), and considering emerging technologies that allow for more discreet visual integration. Main attention is given to locations where renewable technologies collide with architectural composition and public space quality. The comparison between surface-mounted installations and integrated solutions highlights the potential of design-oriented approaches to reduce the negative impact of renewable energy installations on the quality of urban space. The findings indicate that the absence of spatial and design guidelines significantly increases the risk of visually intrusive and context-insensitive solutions.

Taking everything into consideration, a set of qualitative design recommendations for the localisation of small-scale renewable energy technologies in the urban environment is proposed, addressing both visual and efficient features. The conclusions emphasise the need to consider renewable energy technologies as an integral part of urban and architectural design, which may help lessen spatial conflicts and improve the comprehensive quality of the urban environment.

The heat pump boreholes' filling thermal conductivity influence on their required length

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Heating buildings using renewable energy sources is a commonly known concept. Brine/water heat pumps have been successfully used in residential, commercial and industrial buildings. With the development of technologies that allow for the generation of electricity from renewable sources locally and on a fairly large scale, the use of heat pumps has become even more environmentally friendly. Technologies and research related to Thermal Response Tests (TRT) are developing, and simple simulation tools such as Earth Energy Designer (EED) are already widely used due to geological databases development. The construction of vertical boreholes for ground source heat pumps accounts for a large share of the investment cost, and appropriate grouting has great influence on system performance. Therefore it is becoming increasingly important to accurately dimension borehole heat exchangers, especially in medium and high-power systems.

The dimensioning of ground sources for brine/water heat pumps continues to be an interesting topic for scientists. The subject of the study is the analysis of the influence of high thermal conductivity materials, used for ground-source heat pump boreholes filling, on their dimensioning. The research was conducted for the system based on two ground-source heat pumps with a total heating power of 76 kW, intended to meet the multifamily building's energy demand for space heating and domestic hot water throughout the year. Basic parameters of the ground heat exchanger, including borehole and pipe diameters, as well as the boreholes' field configuration were provided, taking into account assumed ground properties and required flow through the lower heat pump source. A commercially available probe was taken into account. The required length of a single borehole was calculated using EED simulation software, with the assumption that the glycol in water solution temperature will not drop below 0°C. A number of borehole filling materials with different thermal conductivities were analyzed. The savings generated when using high performance filling materials were calculated. It came out that using high performance materials may shorten the required length of the heat exchanger by 6%, to as much as 9%. Using high performance filling materials available on the market allows for saving a few percent of investment costs, which in the case of a medium sized system may amount to several thousand zlotys.

Evaluation of the energy and ecological effects of a photovoltaic--thermal system

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The increase in the share of renewable energy sources in the building sector is important to reduce greenhouse gas emissions. One of the possible actions in this regard is the use of installations with hybrid solar collectors, which create optimal working conditions for solar cell batteries and allow the recovery of waste energy in the form of heat. There are few studies in the literature presenting quantity of energy yields from PV/T panels in temperate climates as well as promoting their applications. Therefore, this paper bridges this research gap.

On the basis of simulation studies using TRNSYS 16 software, a detailed analysis of operating parameters of a solar installation with photovoltaic-thermal collectors (PV/T) in a single-family house with a cubic capacity of 826 m^3 was introduced. The solar installation consists of seven hybrid solar collectors PV/T with a total area of 14 m^2. The efficiency of photovoltaic conversion was assumed to be 15.5%. The annual electricity demand for the building was determined at 3727.43 kWh/year. Daily domestic hot water demand was assumed at the level of 350 dm^3/d. Comparative analysis of operating parameters was carried out for two locations: Warsaw (Poland) and Andravida (Greece).

The electric power of the solar installation reached the highest values in the range from 0.86 kW to 1.138 kW in the period from April to September for Warsaw, and for Andravida from March to October in the range from 1.05 kW to 1.123 kW. The average annual value of the electrical power of the solar system operated in Warsaw amounted to 0.355 kW, and in Andravida to 0.447 kW. Considering the months with the best sunshine, from May to August, the average monthly electricity yield in PV/T solar collectors was 206 kWh (Warsaw) and 248 kWh (Andravida). In July, the hybrid solar installation under Polish climate conditions covered 82% of the building's electricity demand, and under Greek climate conditions in 99%.

The highest average monthly working fluid temperature in a circuit of solar hybrid collectors was 45.7°C, and the highest water temperature in a storage tank with a capacity of 500 dm^3 was 35.2°C, and for the solar installation located in Andravida these temperatures were 60.2°C and 45.2°C, respectively. Heat recovery from PV/T solar collectors in July in the climate of Greece was estimated at 264 kWh and was 29% higher compared to heat recovery in the hybrid solar installation located in Poland.

The generation of electricity in the PV/T solar system can contribute to reduction of the annual emissions of pollutants by: 19 kg of SO_2, 0.99 kg of NO_x, 44.55 kg of CO, 1980 kg of CO_2, and 25.25 kg of particulate matter.

Design optimization and modal analysis of helical savonius vertical-axis wind turbine composite blades

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This article presents an integrated research study of the modern Vertical-Axis Wind Turbine (VAWT) design optimization, system modeling, and dynamic analysis of the optimized VAWT composite blades. Furthermore, this study investigates and assesses the impact of various elected VAWT composite blade configurations in addition to dominant design factors such as the aspect ratio (AR) and helix angle (ϕ) on the VAWT performance. Taguchi technique with additive modeling is employed to arrange the VAWT design variants, enhance the modal analysis procedure, elect the dominant helical Savonius-VAWT (S-VAWT) design factors, and assess the optimal settings of the dominant design parameters. The elected S-VAWT composite blade configurations are designed, modeled, and simulated within the SolidWorks Simulation 2023 package. Modified mechanical characteristics of Carbon/Glass – Polyester VAWT composite blades are presented using the lamination plate theory to enhance the scalability, reliability, durability, and accuracy of the designed models. The numerical finite element models (FEM) are generated to model, visualize, and predict the dynamic characteristics (such as modal frequency and mode shape) of the optimal composite blade configurations. Based on the arranged analysis outcomes, Response Surface Methodology (RSM) is incorporated to generate the mathematical modeling of the performance characteristics in terms of the VAWT design parameters. The research study's outcomes highlight the significant impact of the optimal VAWT composite blades in enhancing the dynamic characteristics of modern VAWTs. It's concluded that the aspect ratio, with a contribution of 73.82%, and the composite blade configuration, with a contribution of 18.47% play a significant role in controlling and enhancing the frequency response of the helical S-VAWT composite blades.

A state of the art on the application of nanofluids for the development of highly efficient solar collectors

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As the pursuit of substantial energy escalates, solar collectors have emerged as a pivotal technology for power generation, water heating, space heating, desalination, etc. Conventional heat transfer fluids in solar collectors often act as a hindrance, limiting the potential performance of the solar thermal system due to their innate thermal restrictions. Nanofluid based solar collectors are gaining prominence as a potential substitute to traditional fluids due to their higher thermal efficiency and improved energy utilisation. This review aims to delve deep into the evolving field of nanofluids- carefully designed nanoparticle suspensions, as a promising approach for mitigating the inherent limitations, with the target of boosting the thermal efficiency of solar collectors. A survey of recent insights from both hands-on experiments and simulations shows a consistent pattern of improvised heat transfer and a higher efficiency across several solar collector designs. However, there are several obstacles that limit the widespread adoption of this technology. The primary aim of this study is to evaluate the performance variation across various nanofluid-solar collectors. The notable developments achieved in augmenting the key thermophysical properties, particularly thermal conductivity and specific heat, by scattering a range of nanomaterials such as metal oxides, carbon allotropes and innovative hybrids are examined. These enhancements facilitate more adsorption and transport of solar energy, contributing in substantial improvement in the overall solar collector efficiency. Despite these advancements, some major obstacles such as long-term colloidal stability, nanoparticle agglomeration and the rise in viscosity remain a constraint to large-scale deployment.

The analysis of the existing literature shows a clear path forward: these challenges are not insuperable and can be resolved through fine-tuned stabilization techniques, such as careful pH adjustments, a smarter application of surfactants and erudite surface modifications. In conclusion, the evidence strongly suggests that stable and thoughtfully formulated nanofluids are a key component for engineering the next generation of highly efficient solar energy technologies.

Best practices for using artificial intelligence in research laboratory “Digital Energy Systems 4.0”

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In the context of rapid digital transformation and increasing demands for energy efficiency, sustainability, and system reliability, Artificial Intelligence has emerged as a key enabling technology for modern digital energy systems. The integration of AI-based methods and algorithms into energy system monitoring, control, and optimization offers significant potential for improving grid resilience, reducing operational losses, and facilitating the efficient integration of renewable energy sources.

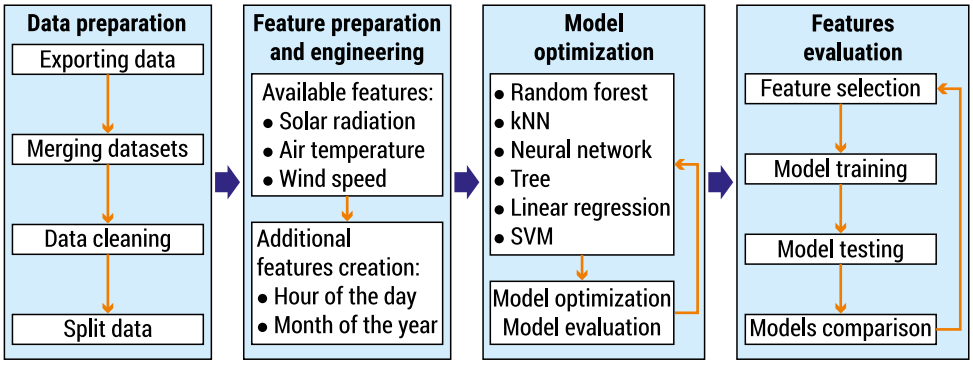

FIG 1. Overview of the used methodology

In Data preparation a dataset is generated by exporting it from different sources, cleaning it and splitting it into training and validation datasets. Feature preparation and engineering includes main features used, which are the solar radiation, the air temperature, and the wind speed. Furthermore, two additional features are generated: the hour of the day and the month of the year. Model optimization is related to algorithms to optimize repeatedly by tuning up their hyperparameters, in order to achieve highest accuracies. Features evaluation – the models are trained with different combinations of features in order to obtain the optimal combination.

Despite the significant benefits, the practical deployment of AI in digital energy systems raises a number of technical and organizational challenges. These include data quality and availability, model interpretability and robustness, scalability of algorithms in large-scale systems, and compliance with regulatory frameworks. Consequently, the identification and implementation of best practices are essential to ensure that AI solutions are reliable, transparent, and aligned with the safety-critical nature of energy infrastructures. Best practices encompass not only algorithm selection and model training procedures, but also system architecture design, data governance, validation and verification methodologies, and lifecycle management of AI-enabled applications.

This article aims to present and analyze best practices for the use of artificial intelligence in digital energy systems, with a focus on research-based solutions, real-world applicability, and future development perspectives. Particular attention is given to methodologies and approaches aligned with the research priorities and innovation orientation of the University of Ruse, supporting the transition toward smarter, more sustainable, and digitally enabled energy infrastructures.

C. RETROFITTING & DECARBONIZATION STRATEGIES

New ecodesign requirements for commercial space heaters and the decarbonisation process

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Ecodesign means taking environmental aspects into account when designing a product in order to improve the environmental performance of energy-consuming products throughout their life cycle. All space heaters should be subject to ecodesign requirements, which ensures a high level of energy savings. In order to increase the representativeness and relevance of ecodesign requirements and to eliminate ambiguities and existing legal loopholes in relation to products that provide thermal comfort, on April 18, 2024, the European Commission issued Regulation 2024/1103, which repeals the previous Regulation 2015/1188. A new regulation comes into force in Poland in July 2025 and refers to ecodesign requirements for local space heaters and separate related controls. Local space heaters intended for commercial use are luminous local space heaters and tube local space heaters. In the context of these space heaters, the aim of the study is to discuss the key provisions introduced under the new regulation and their significance for decarbonization. The results of the analysis of the rules introduced in the regulation indicate five key changes, namely: 1) the scope of equipment covered by the regulation, 2) increased requirements for energy efficiency and pollutant emissions, 3) requirements for energy consumption modes, 4) obligations regarding maintenance and availability of spare parts, and 5) requirements for product information. Based on the conclusions from the analysis of the changes introduced in the regulation, it can be concluded that certain types of heaters had to be withdrawn from manufacturers' offers because they do not meet the current ecodesign requirements. It is estimated that the measures envisaged in the ecodesign framework could lead to significant final energy savings by 2030. This corresponds to a reduction in greenhouse gases emissions and electricity savings.

Modelling a ground heat exchanger based on an existing facility as a model

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A Ground Source Heat Pump (GSHP) is a technology that can be used to provide heating/cooling and hot water supply at a stable lower heat source temperature. However, an incorrectly designed lower heat source for the ground heat pump – the ground heat exchanger (GHE) – can significantly increase operating costs. Under the current design approach each component of a GSHP system should be designed separately. To optimize the different system components for the thermal behaviour of the ground and the ground heat exchanger (GHE) we need an integrated approach that allows us to model the system as a whole. This paper presents a proposed model of GSHP systems and tests it on an existing GSHP system in northeastern Poland. In the model, the GHE is simulated using a computational model that can quantitatively predict temperature changes in the ground heat exchanger and the surrounding soil. Due to the lower outdoor air temperatures in the analysed area, the operation of the system's ground heat exchanger was compared for different actual outdoor air temperatures. System stability can be a good alternative to air source heat pumps for areas with lower average outdoor air temperatures.

The results obtained were compared with field measurements taken at the site. The consistency between the modelling results and the actual data demonstrates the ability of the integrated model to simulate thermal systems with a reasonable level of accuracy.

An analysis of carbon sequestration potential through a green roof applied to a public library in Romania

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Romania is currently undergoing an accelerated urbanisation process, characterized by a significant increase in new building construction to meet growing societal demands. This trend of high-density urban development leads to the concentration of carbon dioxide (CO_2) emissions within metropolitan areas, exacerbating local environmental pressures. Among the sustainable urban design strategies, green roofs represent an effective nature-based solution for mitigating atmospheric CO_2 concentrations. Green roof systems function as passive environmental technologies through the combined action of vegetation and substrate layers, which facilitate photosynthetic processes and enable carbon sequestration from the surrounding atmosphere.

The objective of this study is to quantify and comparatively assess the CO_2 sequestration potential of a green roof system implemented on a public library building in Romania, with the aim of estimating its contribution to local atmospheric CO_2 reduction. The analysis evaluates the annual amount of CO_2 sequestered by the green roof and compares these results with the CO_2 emission reductions achieved through the implementation of conventional photovoltaic panels used for on-site energy production. The findings provide a comparative perspective on the effectiveness of biological versus technological mitigation strategies in reducing the carbon footprint of public buildings in urban environments.

Hygrothermal assessment of the use of recycled materials in internal insulation systems

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This article discusses the potential use of polystyrene waste for the production of thermal insulation panels for use in the energy retrofit of historic buildings. The aim of the research was to develop an insulating material from recycled materials and evaluate its thermal and moisture properties under laboratory conditions and in actual use.

The article emphasises the importance of recycling in construction and the need to seek solutions that reduce the consumption of energy and raw materials. This problem is particularly significant in historic buildings, where external insulation is often impossible, so internal insulation is used, requiring materials with appropriate physical parameters.

The panels were developed using regranulated polystyrene, Portland cement, polypropylene fibers, and modifying additives. The resulting composite has a porous structure, ensuring good thermal insulation while maintaining the required strength. Laboratory tests determined, among other things, the thermal conductivity coefficient, density, water absorption, vapor permeability, and mechanical strength. The thermal conductivity coefficient of approximately 0.047 [W/mK] confirmed the suitability of the material for thermal insulation applications in internal insulation systems.

Laboratory tests were supplemented with in situ analyses carried out in the building envelope undergoing thermal retrofit. Sensors were installed in the wall layers to continuously measure temperature and relative humidity, allowing the assessment of variability in thermal and humidity conditions and the risk of condensation between layers. In addition, annual temperature monitoring was conducted on the inner wall surface using the contact method. The results showed small differences between the internal air temperature and the surface temperature – a maximum of approximately 1.0°C in winter and up to approximately 0.5°C in summer, which indicates stable thermal conditions of the partition.

The analyses were supplemented by calculations of the thermal transfer coefficient and thermal inertia, which indicated that temperature fluctuations primarily affected the insulation layer, which effectively reduces heat loss but has limited energy storage capacity.

Another important element of the research was the determination of the mass moisture content of the partition layers using the gravimetric method. An increase in the moisture content of the insulation toward the external environment was observed, with the highest values at the adhesive layer. The profiles obtained did not indicate any threats to the durability of the system.

The tests confirmed that panels made from polystyrene waste exhibit favorable thermal and moisture properties and stable operational behavior. They can be an effective and ecological solution for the thermal modernization of historic buildings, aligning with the principles of a circular economy.

Efficiency of heat and cold storage in buildings

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In effective and sustainable energy management in buildings, it is crucial to reduce energy consumption and losses at the stage of generation, distribution, and regulation of technical systems. Energy demand in buildings – primarily for heating, ventilation, hot water preparation, cooling, and lighting – is characterized by significant daily and seasonal fluctuations. This variability results in increased peak power and reduced energy and economic efficiency. Load imbalances can be compensated for, among other things, by using energy storage facilities, which allow the energy generation process to be shifted in time relative to its consumption. As a result, the energy resilience of the building increases, which improves the cooperation of low-emission sources with optimal energy use, e.g., during periods of more favorable operating conditions for the installation or lower energy prices. In buildings, energy storage is most often implemented in the form of heat and cold storage using sensible heat, latent heat (PCM), and thermochemical processes.

The aim of the work is to assess the efficiency of heat and cold storage in a single-family building with an air source heat pump for selected technological solutions, understood as: a central heating system buffer, a domestic hot water tank, and the use of the thermal inertia of the floor in a controlled pre-heating and pre-cooling mode. The methodology is based on variant analysis and indicators: useful storage capacity, energy that can be shifted in time, and potential peak power reduction. In addition, the analysis includes a comparison of standard control with tariff control, in which part of the heat pump's work is deliberately transferred to a cheaper zone.

The results indicate that in the adopted control scenario, heat storage in the buffer and tank allows the peak power consumed by the system to be reduced by approximately 25% (compared to the typical peak electrical power of the compressor in the analyzed installation class). The economic effect in the tariff system shows that transferring part of the energy consumption from the more expensive daytime zone to the cheaper nighttime zone reduces the cost of this transferred energy by about 53%, which translates into annual savings of several hundred zlotys for a typical heating season. The conclusions include recommendations for the selection of storage capacity and control principles for single-family buildings with heat pumps, taking into account the possibility of short-term storage of cold in the building mass during the summer. Heat and cold storage is an important, yet still underestimated, element of decarbonization in the construction sector.

Comparative analysis of building energy performance using steady-state and dynamic simulation methods

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This study presents an energy performance analysis of a single-family residential building located in Białystok, Poland, designed and constructed in accordance with the NF15 energy standard, corresponding to the passive building standard (EUH < 15 kWh/(m²·year)). The calculated energy demand was compared with measured operational energy consumption to evaluate the accuracy of simulation results.

To assess the influence of climatic conditions on building energy performance, additional analyses were performed for the same building model located in different regions of Poland and in Udine, Italy. Two computational approaches were applied: the Audytor OZC 7.0 Pro software based on the steady-state energy balance method, and DesignBuilder using the EnergyPlus dynamic simulation engine.

The results indicate that simplified balance methods, such as those implemented in Audytor OZC, tend to overestimate instantaneous heating and cooling demand due to the omission of building thermal inertia. Although these methods are widely used in Poland for building energy certification and are suitable for smaller buildings with limited zoning, more advanced simulation tools provide higher accuracy by incorporating dynamic thermal behavior and detailed climatic parameters.

The comparison of results obtained from the two calculation tools revealed differences of up to several percent, primarily due to variations in climatic data and computational algorithms. The findings confirm that advanced simulation tools are necessary for accurately assessing modern building technologies and complex energy systems. Moreover, the selection of envelope improvements, technical systems, and renewable energy solutions aimed at transitioning buildings from nearly zero-energy to zero-emission standards should be carefully adapted to local climatic conditions.

Life cycle assessment of pilot and full-scale constructed wetlands for low-carbon wastewater treatment

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Constructed wetlands (CWs) are widely recognised as low-energy wastewater treatment technologies and are increasingly considered within decarbonisation strategies for the built environment. For such systems, the construction phase can contribute substantially to the overall environmental profile due to their limited operational energy demand. However, construction-related impacts are often insufficiently quantified, particularly when comparing different implementation scales. The objective of this study is to quantify and analyse the environmental impacts associated with the construction of CWs at pilot and full scale, to identify the main impact drivers and assess the influence of system scale on construction-phase environmental performance. A process-based Life Cycle Assessment (LCA) was conducted in accordance with ISO 14040–14044 standards, applying a cradle-to-construction system boundary. The study was developed within the LIFE4ZOO project and includes two case studies: (i) a pilot-scale installation in Barcelona (Spain) with vertical and horizontal wetland units (0.01 m^3/h), and (ii) a full-scale constructed wetland in Liberec (Czech Republic) with a capacity of 4 m^3/h. Detailed life cycle inventories were compiled for all construction activities, including site preparation, excavation, material production, transport, installation, and demolition. Background data were sourced from the Ecoinvent database. Environmental impacts were evaluated using the ReCiPe midpoint (H) method, considering categories relevant to climate change, resource use, eutrophication, acidification, and water consumption.

The results show that construction-phase impacts are significant for both scales and are largely driven by material-intensive and earthwork processes. In the pilot-scale installation, protective elements and vertical wetland units present the highest contributions, mainly due to steel, wood, and transport requirements. In the full-scale system, excavation, soil relocation, and construction/refill dominate most impact categories, including global warming potential, fossil resource scarcity, and water consumption, while paving and pipe installation are relevant contributors to eutrophication and mineral resource scarcity. Although total impacts increase with system size, the relative contribution of construction activities reveals consistent environmental hotspots across scales. These findings demonstrate that, for low-energy wastewater treatment technologies such as CWs, the construction phase constitutes a key component of environmental performance. Applying LCA at early design stages enables the identification of priority actions for impact reduction through optimized construction practices and material selection, supporting the development of low-carbon wastewater treatment infrastructure.

Minimising spatial footprint in decentralised water treatment: A techno-economic evaluation of GO-functionalised MBRs

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To improve urban resilience and protect blue and green infrastructure, decentralised indirect reuse of drinking water (IPR) is essential. Overcoming conventional biofouling, this research assesses the technical and economic feasibility of upgrading membrane bioreactors (MBRs) with graphene oxide (GO). To assess their operational and financial performance, laboratory-scale data from GO-modified membranes were validated using steady-state computational models (Aspen Plus® V14). By simulating mass/energy balances and separation efficiency, this approach enables a robust technical-economic analysis (TEA) of the decentralised platform at full scale.

The TEA demonstrates that upgrading from a conventional system (CAS) to a GO-adapted MBR offers fundamental advantages. High biomass operation reduces reactor volume by 66% (from 24 to 8 m^3), representing a 76% reduction in civil capital expenditure (CAPEX) (€10,560 vs €44,880). Although energy and reagent requirements increase the operating costs (OPEX) of the MBR (€24,506/year), the 38% reduction in sludge management partially offsets this increase. It is essential to note that internalising the externalities of blue-green ecosystems reveals that the MBR almost doubles the monetised environmental benefits (€12,040 vs €6,937/year).

In conclusion, although GO-adapted MBRs involve higher energy demands, their ability to reduce space requirements by 66%, drastically reduce civil capital costs, and double monetised environmental benefits makes them a solid and economically viable pillar for resilient blue-green urban infrastructure.

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D. SUSTAINABLE ARCHITECTURE & GREEN INFRASTRUCTURE

Towards sustainable architecture and green infrastructure in the renovation of university buildings

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University buildings embody both cultural heritage and future-oriented educational missions, making their renovation a critical challenge for sustainable architectural practice. This paper investigates how green infrastructure and human-centered design strategies can be integrated into the renovation of university buildings to balance environmental performance, social well-being, and the continuity of architectural identity. Through a comparative set of European case studies, located at Bialystok University of Technology in Poland, University of Banja Luka in Bosnia and Herzegovina, University of Girona in Spain, University of Perpignan in France and University of Udine in Italy the research examines internal courtyards, patios, and connective spaces as key interfaces between historical fabric and contemporary architectural interventions. Particular attention is given to heritage university buildings, where new elements (such as glass connectors and redesigned courtyards) act as mediators between past and future, enhancing spatial legibility, daylighting, and environmental comfort while preserving cultural values.

The analyzed projects demonstrate how green patios and courtyards contribute to urban cooling, biodiversity, and microclimate regulation, while blue-green infrastructure supports water management and resilience. In parallel, the study highlights human-centered renovation approaches that improve accessibility, inclusivity, and everyday comfort in historically constrained academic environments. By framing university renovation as a process of architectural continuity rather than replacement, the paper proposes transferable strategies for embedding sustainability and green infrastructure within heritage contexts. The findings position renovated university campuses as living laboratories where environmental responsibility, cultural memory, and future academic needs converge. In addition, these spaces act as educational agents in their own right, indirectly contributing to the learning and awareness of the students who pass through them.

A conceptual design framework for rooftop gardens and well-being

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The comfort and well-being of urban residents is a challenge of this century, which cities must overcome by thinking about human-centered infrastructures. Rooftop gardens are a relatively a new type of green space, designed for urban agglomerations, where population density is increasing. Research indicates that green roofs are effective in mitigating heat stress, but also in improving the energy efficiency of buildings. This method of urban greening must be planned and designed also as a connection of residents with nature, taking into account the influence of shapes, colors, texture and vegetation, not just as an ecological infrastructure. This paper relies on studies related to plant design, but also psychology, creating a framework and a 3D design of a rooftop garden, with the aim of guiding architects, landscapers, gardeners and residents in the development of such green spaces.

In landscaping, the aesthetic effect, the visual, is predominant, however, centering the man in the midst of nature and his well-being, designers must also take into account the auditory, olfactory, tactile and gustatory senses in planning a green space, thus emphasizing the cognitive effects that they generate. The correct and harmonious use of vegetation elements can also change the behavior of residents, for example, borders, flowerbeds with aromatic plants or fragrant flowering trees can discourage residents from throwing garbage on the ground. Even though the perspective of residents is different from one individual to another, the right combination of colors is a necessity in a gloomy and gray urban environment. Warm colors are dynamic, express vitality and can be observed from a distance, while cool colors have relaxing effects. Through interaction with nature, our attention is restored, thus the lack of perception, interest, anxiety or stress disappears being replaced by the feeling of fascination that arises in the subconscious involuntarily, the landscape having foundations based on the cultural concept and belonging, but also on the biological-evolutionary concept. The functionality of the rooftop garden can be diverse, depending on the needs of the residents it addresses, it can include elements of therapeutic gardens, it can function as a community garden, it can focus on edible landscaping, or it can function as a garden for relaxation. When planning a rooftop gardens the key is to create a dynamic relationship between aesthetics, ecology and science. In the urban agglomeration, a rooftop garden can generate a sense of freedom, being a place where you can take a break from work or daily life. The residents' connection with nature is created through a rooftop garden built on principles of controlled naturalism and apparent spontaneity. Even if human intervention is major, the viewer must be given the illusion of a landscape born in situ, in which the vegetal stratification and spatial composition support an urban forest atmosphere, diminishing the perception of artificiality and it's positioning on the roof.

Urban fabric and opportunities for harvesting energy

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The aim of this paper is to analyze the concept of urban fabric in the context of a sustainable design, focused on the way the energetical flux and resources flow of the city are used in the built environment. In this sense, the research will connect the spatial aspect of urban design with the local demand and emergent technologies.

Through its cognitive potential, architecture is extremely important in the education of individuals and society. Between the basic elements of the architectural language, the form, the space and the voids could be considered. Valences of spaces as results of voids are the main topic of this research. It aims to tackle the issue of qualitative design of the void space and how it should be approached from a morphological point of view. The links between space, social dynamics, contextual needs and their implications on overall morphology will be another aspect to be debated in the frame of urban fabric concept to transform cities into productive systems. It is certain that public space over time incorporated different meanings and forms, representing the cobblestone regarding cities, urban morphology, urban dynamics and urban design. In this respect, this paper initiates a discussion about voids seen as transitory elements in a spatial sequence. To better understand transitions, relevant in this sense is analyzing the spatial sequence and spatial experience defined by the opportunity of shift from "Public Space to Energy Harvesting Public Space".

Public spaces, as tools for measuring and enhancing the degree of comfort, living conditions and communication were always key elements in expressing the features of the city. Therefore, the design of public spaces must consider on one hand social dynamics and on the other hand psycho-sensorial behaviour in experiencing the space. In this respect, two concepts will be introduced: Social Content and Social Container. The interaction between those will underline the effects and distortions that Social Content has on the architectural space, especially on the void-space. Voids, as an architectural component, will be considered as the Social Container, representing the materialization of society's desires and aspirations. The spatial investigation procedure will be based on Gestalt method, and for the social analysis aspects of social design thinking will be used. Through a case study will be analysed the void in urban fabric as an operating element, as a way of digging in the mass of solid and finally, as a transition element aimed to choose the best and coherent integration at level of intervention.

As a conclusion, a good urban organization will require well defined architectural patterns and all the missing links, which determine discontinuities in urban fabric, must be seen as opportunities to develop new interventions.

Global challenges in positive energy districts deployment and novel strategies for unlocking building-level energy recovery from wastewater

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As the world is moving towards climate-neutrality, the development of Positive Energy Districts (PEDs) is playing a pivotal role in the achievement of the ambitious targets of the European Strategic Energy Technology -SET Plan. As an integral part of the decarbonization strategies for cities and urban sector, positive energy districts are seen as urban areas with net zero CO_2 emissions and a net zero energy import able to efficiently manage energy production surplus from green resources. European municipalities and urban communities are working together to develop feasible pathways for creating sustainable and livable positive energy urban neighborhoods but diverse and complex challenges, mainly arising from the lack of practical experience, still need to be addressed.

In this framework, the present research article, developed in the framework of the project PAID-06-25 financed by the Vice-Rectorate for Research of the Universitat Politècnica de València, proposes a novel holistic approach to assess technical, economic and social factors that affect the current status of the deployment of Positive Energy Districts among European countries. The main innovative strategies adopted for balancing technical building needs with social, economic, and environmental aspects have been identified together with the main challenges that still prevent the deployment of zero-net emissions districts and building energy surplus management. Furthermore, in line with the UN's 2018-2028 Water Action Decade Renewed with a special focus on water security, holistic solutions employing wastewater as a resource for the sustainable development of small communities of PED has been identified. Moreover, the role of Wastewater Treatment Plant as positive decentralized energy hub, able not only to produce power and valuable nutrients, but also to provide water reuse for multiple purpose has been analyzed.

The results highlighted the lack of energy planning culture, approved governance models together with the high initial investments, and social and regulatory hurdles as the main issues that still need to be overcome. Moreover, the requirement of a full integrated planning for renewable energy maximization, and the adoption of reliable energy efficiency measures have been highlighted as crucial for PED deployment as smart, flexible parts of a larger energy system, using integrated technologies to manage local energy flows, store surplus energy, and be able to balance consumption with production. Finally, the main achievements of ongoing European initiatives will be presented. The findings show that positive energy waste water treatment plant, especially if implemented in small communities (less than 50,000 inhabitants), can be a crucial infrastructure for PED deployment able to turn sewage into a valuable energy and resource stream such as recovery water and recovery energy, which can then be used for heating/cooling at a building level.

GreenInCities in Nova Gorica: Between the artificial and the natural

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Paradigms of urban management are changing as societal values directly influence local politics. In an age of rising service costs particularly the management of municipal urban green spaces opens up the space for alternative governance models and strategic use of nature based solutions (NbS). Besides long term economic benefits, NbS coupled with consistent citizens engagement, can significantly lower service fees and build societal cohesion, provided local administrative bodies commit to citizens outreach programs and dedicate time and human resources towards systemic (legal as well as organizational) changes.

The GreenInCities project is a cross European initiative dedicated to transforming, creating and re-imagining five European parks. Under Horizon Europe funding, Barcelona, Athens, Helsinki, Prato and Nova Gorica will serve as a model for future urban management policies.

Nova Gorica's project priorities are based on its unique history, geography and urban atmosphere. An ex nihilo city, built as a political project of the Socialist Federal Republic of Yugoslavia, it is one of few examples of a fully modernist urban scheme, featuring the idea of blocks, dotted in the 'park'. Its precursor and neighbor, the historic city of Gorizia emphasizes the ideological difference of political regimes with a fundamentally disparate urban layout and subsequently different spatial hierarchy of natural and artificial environments. Nova Gorica, unlike historic European cities, has no waterfront. Its equivalent is a sewage channel built as communal infrastructure for the new city on its southern border, named the Koren stream. Its waters were polluted until recently, opening up the possibility for a publicly accessible waterfront in the center of the city, encouraging the project's team to advocate for the enlargement of the Koren stream basin as well as its naturalization in the part of the channel surrounded by 60 000 sqm of unbuilt, practically untouched land, neighboring one of the first housing estates of the city.

The project's challenges fuse complex local dynamics with overarching institutional regimes, emphasizing the role of social spaces designed for citizens whose sense of communal belonging was lost due to old age or changing social atmospheres. The reinstating of the commons, historically a name for pasture and forested grounds available for everyone's use, is faced with multiple challenges. Can a productive landscape resist commercialization or decay? Can citizens benefit and take responsibility for the management of our commons? The project commits to creating an edible landscape, a common ground for feeding its citizens in an attempt to give green spaces to basic human needs for healthy and socially fulfilling sustenance.

Landscape over architecture. Environmental strategies and nature--based solutions in the urban fabric of Buenos Aires

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The City of Buenos Aires currently provides an average of 6 m^2 of green space per inhabitant, falling significantly below the 10–15 m^2 range recommended by the World Health Organization. As urban density increases, the systematic reduction of permeable surfaces exacerbates the urban heat island effect and diminishes the city's capacity to manage intense, concentrated rainfall. Within this context of global urbanization and escalating energy demands, this paper explores "naturbanization", the intentional integration of nature as a fundamental structural component of the urban fabric.

By implementing Nature-based Solutions (NbS), cities can foster climate change adaptation, enhance thermal comfort, and mitigate pollution. This research examines the deployment of NbS to achieve essential ecosystem services through strategies such as the expansion of green areas on both natural soil and concrete slabs (green roofs), the maximization of absorbent surfaces, the restoration of wetland systems and rainwater harvesting for irrigation.

This study analyzes selected architectural and landscape projects in Buenos Aires to identify their technical and environmental components.

The methodology focuses on three critical layers of integration:

1. The technical layer (Structural and constructive feasibility): Evaluates the structural load-bearing capacity, advanced waterproofing membranes, and drainage systems, utilizing multi-layered geocomposites and recycled polyethylene panels with integrated water retention. It also addresses water management strategies for rainwater harvesting and irrigation.
2. The environmental and vegetative layer (Ecological performance): Analyzes soil depth, composition and logistics, alongside the selection of native and adapted vegetation species. The focus is on drought-tolerant vegetation that reinforces ecological corridors and supports habitat continuity for local biodiversity.
3. The functional and spatial layer (Social Agency & Programmatic Organization): Investigates how spatial configurations respond to microclimatic conditions, ensuring that ecological continuity is integrated with urban identity and social use.

Ultimately, this paper argues that linking these localized interventions into a cohesive "Green Network" strengthens Green & Blue Infrastructure, fostering a more resilient, healthy, and liveable urban environment.

Edible productive urban landscapes as components of sustainable green infrastructure, Breathe | Respirar – Breathe & Feed

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Contemporary cities concentrate over half of the world's population and operate as complex socioecological systems in which biophysical, social, economic, and institutional processes intersect. In Argentina, where more than 92% of the population resides in urban areas, this condition intensifies pressure on urban ecosystems, accelerates ecological fragmentation and biodiversity loss, degrades environmental quality – particularly air quality – and generates adverse impacts on human health and well-being. These dynamics reinforce a structural disconnection between society and nature, which becomes especially critical during childhood, as everyday experiences with ecological cycles and food systems are increasingly mediated by highly artificialized urban environments.

Within the theoretical frameworks of ecological urbanism and socioecological systems, green infrastructure is understood as a functional component of urban metabolism, capable of integrating ecosystem services, social practices, and educational processes. In this context, Nature-Based Solutions and edible productive urban landscapes emerge as integrative strategies for climate adaptation, environmental improvement, and the construction of healthier and more equitable cities. As Zeunert (2017) argues, the incorporation of productive landscapes into the urban fabric enables a reorientation of environmental education toward situated, experiential, and food-system–oriented practices, integrating ecological, spatial, and pedagogical dimensions.

From this perspective, schoolyards can be conceptualized as strategic urban micro landscapes – microscale socioecological nodes embedded within broader green infrastructure networks – with high potential to foster early ecological literacy, experiential learning, and biocultural reconnection. Building on this framework, the BREATHE / RESPIRAR program and its action line BREATHE & FEED propose an interdisciplinary green-infrastructure approach aimed at transforming schoolyards into edible, health-promoting, and educational gardens. The initiative adopts a participatory, scalable, and replicable model, supported by academic and institutional collaboration at national and international levels.

This document outlines the rationale, objectives, methodology, expected outcomes, and institutional structure of the project.

Extensive green roofs and surface runoff reduction: A case study of a multi-family residential complex

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High-density urban areas are characterized by extensive surface sealing, which significantly limits stormwater infiltration and increases surface runoff. This intensification of runoff frequently overloads local stormwater management systems, contributing to a higher risk of flooding, infrastructure malfunction, and adverse environmental impacts. The aim of this study is to evaluate the potential of extensive green roofs to mitigate these issues in a multi-family residential complex by reducing and delaying stormwater runoff.

The analysis was conducted for a selected residential development, for which surface runoff coefficients were calculated in two scenarios:

- the current state with conventional impermeable roof surfaces,
- a projected scenario in which all roofs were hypothetically converted into extensive green roofs using sedum mats.

The comparison of both scenarios made it possible to determine how green roofs influence the study area's response to rainfall, including the magnitude and rate of surface runoff as well as the degree of relief provided to the stormwater management system.

The results clearly demonstrate that the application of extensive green roofs significantly reduces surface runoff coefficients and distributes outflow over a longer time period. This leads to a measurable decrease in peak stormwater discharge into the drainage system, thereby improving its performance and resilience during intense rainfall events. Importantly, the proposed intervention requires only limited modification of the existing urban fabric while providing substantial improvements in stormwater management for densely built areas.

The study concludes that extensive green roofs represent an effective and easily deployable component of green infrastructure, capable of supporting urban climate adaptation strategies. Integrating such solutions into existing multi-family residential developments enhances sustainable stormwater management and strengthens the overall environmental resilience of urbanized areas.

Sustainable urban design – a case study from Białystok

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This publication presents an analysis of three urban design concepts for a multi-family residential complex located in the post-industrial area of the Skorupy district of Białystok. The aim of this study is to identify the most sustainable approach to the urban design of multi-family housing complexes and to select the design concept that focuses on human comfort and social well-being, by pointing out solutions aligned with the 17 Sustainable Development Goals (SDGs).

The research involved a comparative analysis of the adopted functional–spatial layouts, the amenity and service program of the residential complex, the area-based indicators obtained (site balance), development intensity and population density, site design elements (including the potential of green areas), and the degree to which each concept meets the SDGs.

Three projects were examined: (A) an urban design concept resulting from a site analysis prepared by the Białystok architectural practice 'Inwestprojekt'; (B) a conceptual urban design by the Warsaw practice 'NOA Natkaniec Olechnicki Architekci,' submitted by the investor as an Integrated Investment Plan (ZPI) in accordance with the procedure specified in the Spatial Planning and Development Act; and (C) an BEng capstone project prepared by W. Rybak, Eng within the Spatial Management program at Bialystok University of Technology.

The conclusions and summary of the publication attempt to identify the economic, social, professional, and educational factors that may influence final design solutions consistent with the principles of sustainable development.

Transformation of green areas in multifamily housing developments in the Kawaleryjskie estate in Białystok: A case study

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This publication examines the transformation of green areas in the Kawaleryjskie estate in Białystok. The aim of the article is to analyze changes in the size and quality of green spaces within a multi-family housing quarter comprising five residential complexes developed between 1991 and 2025. The study focuses on assessing quantitative and qualitative indicators related to the share of high greenery, as well as identifying relationships between the structure of green areas and the location of garages and parking facilities within the housing blocks, including the resulting introduction of green roofs.

The research methodology includes a review of literature and legal acts, cartographic studies and GIS data analyses, as well as field surveys.

The results reveal a clear correlation between contemporary design practices concerning the placement of garages, particularly underground parking,and the diversification of biologically active areas, along with the gradual disappearance of high greenery. These changes lead to a decline in the quality of shared outdoor spaces and a reduction in biodiversity within newly developed residential areas.

The conclusions highlight the need to redefine standards for designing green areas in multi-family housing developments in the context of sustainable development principles, particularly in balancing parking needs with environmental and social requirements.

Integrating climate vulnerability into urban planning: Prioritizing blue-green infrastructure and adaptation measures

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Ongoing climate change constitutes one of the most pressing challenges for contemporary cities. They accommodate approximately 70% of the global population and are particularly vulnerable to extreme weather events such as heatwaves, droughts, and intense precipitation. In response, cities increasingly implement adaptation measures, in which Sustainable Architecture and blue-green infrastructure (BGI) play a key role in water management and in strengthening urban resilience. However, urban planning still lacks coherent procedures for prioritizing adaptation actions based on cities' climate vulnerability. As a relatively stable characteristic, shaped by environmental, spatial, and social conditions, cities' climate vulnerability should form the basis for planning and design decisions.

The study covered 19 cities in Poland that developed climate adaptation plans between 2020 and 2026. The analysis included environmental and climatic factors (e.g., location within catchments, topography, exposure to hazards), urban characteristics (e.g., city size, land sealing, urban structure, green areas), and social aspects (e.g. demographic structure, awareness). A comparative approach was applied, combining qualitative and quantitative analyses of the aforementioned vulnerability factors, strategic documents, spatial data, and the results of stakeholder consultations in order to identify common determinants of resilience-building processes, expectations regarding adaptation measures, and to support the development of a procedure for prioritizing adaptation actions.

The results indicate that environmental and climatic conditions are closely linked to both the level of awareness of climate risks and the prioritization of adaptation measures. Adaptation priorities, particularly regarding the role of blue-green infrastructure in comparison to conventional technical solutions, vary depending on the environmental situation and climate exposure of the city. Blue-green infrastructure and nature-based solutions are more likely to be considered effective and implemented when their performance can be supported by measurable technical parameters and when prior implementation experience exists.

Based on the findings, a procedure for prioritizing adaptation measures, including BGI, was developed. The proposed approach integrates climate vulnerability assessment with spatial planning, enabling the identification of context-specific and effective measures. The approach may support decision-making in sustainable urban planning, stimulate water management at the catchment scale and actions towards long-term urban resilience and building the quality of life. Furthermore, it can contribute to the development of urban adaptation strategies and the implementation of nature-based solutions in European cities.

The climate and urban conditions of the bus shelters with green roofs location

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Modern cities are grappling with a number of problems stemming from climate change, the built environment, and residents' lifestyles, including the heavy reliance on passenger cars for urban mobility. One way to address these challenges is to modernise the public transport system. This involves updating the network, rolling stock, service levels and accessibility. An increasing number of cities are incorporating bus shelters with green roofs into their green public transport policies. Leading examples in Europe include Utrecht and Warsaw in Poland, where several hundred such shelters have been installed. Białystok is also a prominent example in Poland. [1] The main benefits of green bus shelters for the urban environment include reduced air pollution, increased oxygen production, rainwater retention, localised climate mitigation and improved biodiversity [2]. To date, literature on this subject has emphasised the cooling effect of bus shelters on hot summer days, with temperatures under the shelters being up to 10 degrees lower than the surrounding area.

This raises the question of whether the temperature under the shelters changes relative to the surroundings during other seasons (outside of summer) and whether these changes are beneficial for passengers. What are the general conditions for locating a bus stop to ensure favourable waiting conditions for passengers? In response to these questions, research was conducted in spring 2024. From March to May, a series of temperature measurements were taken at selected public transport stops in Białystok. The selection of stops for the study was based on criteria allowing for the comparison of structural conditions (green roof, glass roof), climatic conditions and location (proximity to buildings and green areas).

Analysis of the study results showed that, in early spring (March), temperatures were higher under green roofs than under glass roofs. However, in late spring (May), when the ambient temperature increased, the situation was reversed and the temperature under the green roofs was lower than under the glass roofs. In both cases, these conditions were more favourable for passengers waiting at the stop. Furthermore, temperature readings taken near frontage buildings were noted to be more favourable for passengers. In terms of green spaces, the conditions under green and glass roofs were comparable.

In summary, it was found that, in spring 2024 in Białystok, the temperature under shelters with green roofs changed relative to the surrounding area, which was beneficial for passengers. Additionally, it was found that shelters with green roofs are more advantageous in the context of neighbouring buildings than in green areas. This can serve as a guideline for urban planning in Białystok and other cities.

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E. SUSTAINABLE MATERIALS & CIRCULAR ECONOMY

Self-healing epoxy-based vitrimer for sustainable and durable construction

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Despite decades of advancement, delamination damage in Fibre-Reinforced Polymer Composites (FRPCs) remains a major contributor to failure in structural components such as wind turbine blades and civil infrastructure. Consequently, self-healable FRPCs have gained considerable attention in recent years. Among emerging approaches, self-healing based on Covalent Adaptive Networks (CANs), particularly vitrimers, has attracted significant interest due to their ability to repair matrix-related damage through bond-exchange reactions. This mechanism enables the recovery of properties after delamination and matrix cracking, offering a promising route to enhance durability, service life, and sustainability of structural polymer composites. However, despite growing research activity, standardized procedures for quantifying self-healing efficiency and for selecting appropriate thermal treatment protocols remain lacking. In particular, a significant gap persists between structural-scale mechanical testing, which evaluates healing from a performance perspective, and material-scale characterization techniques that probe the molecular dynamics governing the healing process.

In this work, this gap is addressed by evaluating self-healing behavior at both the structural and material scales and demonstrating coherence between them. The study focuses on an epoxy-based vitrimer system formulated at CIDETEC using commercially available diglycidyl ether of bisphenol A (DGEBA) and an aromatic disulfide-based dynamic hardener. At the structural scale, Double Cantilever Beam (DCB) specimens were employed to introduce controlled delamination, apply a defined healing thermal cycle, and quantify recovery through the regained Mode I fracture toughness. At the material scale, complementary rheological measurements were used to characterize network dynamics and flow activation.

The results reveal a direct correlation between macroscopic healing efficiency and molecular mobility, providing a unified framework for interpreting self-healing mechanisms and guiding the selection of thermal treatment protocols. This multiscale approach contributes to improved standardization of self-healing assessment and supports the development of durable, smart, and sustainable construction materials.

Natural materials in the modernization and adaptation of traditional wooden architecture

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Although contemporary building materials are widely available, they do not always support the preservation of traditional wooden architecture. Growing awareness among property owners regarding the care of traditional architectural forms has led to increasing interest in natural materials, including plant-based solutions. The aim of this article is to present plant-derived materials used in the modernization and adaptation of traditional wooden architecture. Particular attention is given to products applied in adapting historic buildings to current technical requirements.

The study draws on an analysis of literature devoted to both natural building and traditional construction. A review of plant-based building materials available on the market was also conducted. The results indicate a wide range of applications for commercially available products capable of replacing synthetic building materials.

These include both classic solutions used for centuries – such as wood, sawdust, flax and hemp tow, straw, and reed – as well as contemporary plant-based materials, including wood wool and cellulose fibers applied using spray technologies. This group also encompasses materials that incorporate plant-based raw components, such as clay–straw boards, hempcrete, clay–straw blocks, and plasters with added plant fibers.

The conclusions suggest that the use of renewable and biodegradable plant-based resources aligns with the principles of sustainable construction. Moreover, it increases the likelihood of preserving the cultural heritage represented by traditional wooden architecture.

Pore-size effects in contaminant adsorption

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Sorption processes, including adsorption and desorption, play a central role in many areas of interest: from the removal of contaminants from fluids to hydrogen storage technologies based on porous materials. The efficiency of these processes depends on the microstructure of the adsorbent, particularly on the distribution of pore sizes. However, most mathematical models rely on homogenized descriptions of porous media and do not account for the internal pore-size distribution. The aim of our work is to develop mathematical models that explicitly incorporate pore-size distributions to capture the impact of porous microstructure on adsorption dynamics and improve predictions of adsorption kinetics and equilibrium in nanoporous adsorbents. In particular, our approach relates it to the adsorption rates of contaminants within a probabilistic description of pore accessibility.

The modeling framework combines multiscale and size-structured approaches to link pore characteristics with macroscopic concentration. We focus on the evolution of contaminant concentration in a batch system containing nanoporous adsorbent particles, where experimental conditions allow for simplified governing equations. Information on pore-size distributions comes from BET characterization of activated carbons in the micro/mesoporous diameter range of 0.6–24 nm, with most of the volume being contained in pores below 2 nm. Internal surfaces can reach 1500–2800 m^2/g. The evolution of contaminant concentration in the batch system is tracked until equilibrium is reached. We repeat the process for several combinations of contaminant size, carbon type, and initial concentration. The resulting concentration curves and isotherms allow model parameter calibration.

Preliminary results show that variations in pore-size distributions can lead to different adsorption dynamics, even under identical experimental conditions. Simplified analytical solutions and numerical simulations suggest that microstructural effects may significantly influence both adsorption rates and equilibrium. This work is ongoing, and forthcoming results will include the study of adsorption efficiency based on the calibrated models for each experimental combination. The proposed framework is flexible and can be extended, for instance, to account for competition between multiple contaminants in future studies.

Utilization of construction waste as components of lime fertilizers

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In recent years, the role of gypsum as a construction material has increased. Consequently, in the coming years, the amount of gypsum waste is expected to grow, and the significance of its recycling is becoming an increasingly serious challenge.

The aim of the study was to determine the most advantageous material, process, and structural parameters used in the pressureless agglomeration of calcium carbonate with waste materials (waste gypsum derived from the milling of gypsumplasterboards and PPR, i.e. postreaction product from flue gas desulfurization), using selected binders that would allow the production of fertilizers of satisfactory quality.

The production of fertilizers through pressureless granulation was carried out at a research stand whose main component was a disc granulator. During the study, the influence of waste gypsum from gypsumplasterboards, added in amounts of 10, 15, and 20% to a mixture with calcium carbonate and 10% waste PPR, was evaluated.

Granules obtained from mixtures of calcium carbonate with waste gypsum and 10% PPR are characterized by a CaO content of 48.3–49.22% and can be classified as lime products derived from limestone processing, belonging to types 05 and 06.

An increase in the content of waste gypsum from 10 to 20% in the mixture with calcium carbonate and PPR resulted in a 5.25% increase in crushing strength (from 6.54 to 6.9 N), an approximately 2.3% increase in bulk density (from 1035.31 to 1059.24 kg/m^3), and a slight decrease in the granulated fraction from 98.56 to 97.67%. No significant effect of increasing the amount of waste gypsum from 10 to 20% on the disintegration time of the granules in water was observed.

The results of the study provide a significant basis for the use of waste materials (waste gypsum from the milling of gypsumplasterboards and waste PPR) as soilapplied components of lime fertilizers.

Europe's circular economy blind spot – rethinking e-waste circularity for critical raw materials security

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Securing access to critical raw materials (CRMs) has become a strategic priority for the European Union amid rising geopolitical tensions, export restrictions, and the material-intensive energy and digital transitions. In this context, the circular economy (CE) is increasingly framed as a key policy approach to reduce import dependencies and enhance resource security. Electronic waste (e-waste) represents one of the fastest-growing waste streams in Europe and contains substantial amounts of valuable and critical raw materials, yet its role within current CE policies remains insufficiently understood.

This paper provides a critical and conceptual analysis of European Union regulations as well as selected national circular economy strategies and roadmaps, using the 9R framework as an analytical lens. Based on a structured qualitative content analysis, the study examines how circular economy principles are conceptualized in relation to e-waste and to what extent the recovery of critical raw materials is addressed.

The findings indicate that the implementation of circular economy concepts in the EU and its Member States remains limited and uneven. Policy approaches predominantly prioritize recycling and, to a lesser extent, repair of batteries, while higher-value strategies such as refuse, rethink, reduce, reuse, remanufacture, and repurpose are weakly developed or largely absent. Moreover, e-waste is only partially conceptualized as a strategic source of critical raw materials, and targeted policy instruments for CRM recovery are rarely articulated. The paper identifies key conceptual and governance gaps and discusses barriers that hinder a more comprehensive circular economy for critical raw materials.

Proof of concept for an innovative ice slurry production method

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In refrigeration engineering and cold supply, the focus has increasingly shifted in recent years toward natural refrigerants such as CO_2, propane and ammonia, as well as environmentally friendly thermal storage systems, for example using chilled water or ice slurry. Ice slurry is an advantageous medium for the storage and transport of cooling energy, as it is pumpable, non-toxic, non-flammable and without environmental harm. However, such systems have so far failed to gain widespread application, except for fishery. A key reason for this lies in the disadvantages and limitations of existing production methods, such as wear on mechanically moving components, the need for a separate refrigeration machine, the use of disadvantageous refrigerants, inefficient operation of refrigeration machines, limited ice production rates, or scalability issues for very large cooling capacities. In previous works the authors presented a novel approach for the generation of ice slurry. The process initially involves the production of a gas–water dispersion at high pressure, which is subsequently depressurized, causing a part of the water to freeze into fine ice particles. The method enables continuous, scalable ice slurry production using natural refrigerants. A demonstrator in pilot-plant scale has now experimentally provided proof of concept of the process. Ice slurry was continually produced in first tests with ice proportions of up to 41%.

This paper describes the demonstrator system, the test procedure and presents initial results. The macro shot photos taken at sight glasses show a homogeneous good quality of the ice slurry with very fine particles. The successful implementation of the innovative method in this demonstrator opens a new possibility for the widespread application of ice slurry e.g. in food industry, air conditioning, district cooling or for process cooling. Here lies a high potential for increasing efficiency, using volatile renewable energy and decreasing environmental impacts.

Reducing loss of energy by properly controlling friction in overall constructions' planning and achieving

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Friction is a physicochemical phenomenon ubiquitous in nature and technology as it is often accompanied by lubrication and wear. In natural environmental conditions it unveils decisively all weaknesses of both planning and materializing the constructions and buildings that emerge thanks to human as well as non-human activities. As for the former certain famous churches such as the Wang church in Karpacz built almost without any nail can be mentioned. In the latter, bird or ants' nests are other examples worth to analyze. All of those constructions invoked employ certain intrinsic and/or extrinsic friction conditions, arising with an aid of load, thus ever present gravitation, that show up efficiently as safe spots for human beings and other living creatures (see Fig.1).

FIG. 1. Birds sitting in a winter time on a roof with an appreciable inclination angle, augmenting by their extremities the friction effect while occupying the tessellated surface of the roof.

It turns out that the very oversimplified Coulomb-Amontons law (with an early ingenious contribution by Leonardo Da Vinci) for friction does not capture all peculiarities and essentials of the rubbing-surface structure, thus the load is not supposed to be (unconditionally) linearly proportional to the friction force [1]. An appropriate example comes out when observing birds sitting on inclined roofs – they always seek with their extremities the fracture's edges to keep track of the gravitation, and thereby to modify the well-known (scholarly) formula that the coefficient of friction (COF) will be represented by a tangent of the inclination angle [1–3], see Picture. Similarly, nests or Wang-chapel-type constructions are employing the beneficial friction effect that leads to energy-saving and money-sparing circumstances.

The main aim of the underlying research is to critically analyze certain over-physical-scales lasting formulae proposed for the modified COFs, starting from the macroscale, then passing over the mesoscale, and finally arriving safely at the microscale [2], thus, when reaching a vicinity of the nanoscale but still upon an involvement of the microgravity effect [3].

The results will uncover practical usefulness of the modified COFs for a number of representative examples already mentioned. From these it can be concluded that an energy-saving and minimal-dissipation (also superlubric viz highly slippery [3]) effect will be unraveled and proposed for serious consideration when starting any construction procedure. In addition, certain processes accompanying the accomplishment of the final effect, such as slippage, networking and transportation friction-and-wear as well as lubrication, or wetting conditions, will be taken into account. Nature's strategy pointing to a biomimetic approach ought to be emphasized as well [4].

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The influence of vertical planting on the surface temperature of a building in the mid-latitude band, a case study

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The effects of climate change in the mid-latitude zone, where the case is being analysed, are associated with temperature fluctuations, unevenness of rainfall, stronger and more frequent winds and its phenomena, the formation of heat islands in urban areas, and the increased risk of occurrence of natural phenomena. The rapid development of urban areas, the lack of territories for the installation of greenery, especially in the cities, force us to look for solutions to improve the microclimate of cities. The application of nature-based solutions based on the use of nature to solve global challenges can increase resilience to climate change, improve air quality, and absorb urban noise. One solution could be the creation of green zones in the city, e.g. green walls and facades. Vertical planting of urban areas not only absorbs part of the city's noise, contributes to the improvement of air quality, but also maintains the right microclimate of buildings during heat, prevents buildings from overheating – which creates prerequisites not only for lower energy cooling needs of premises, but also protects the surfaces of buildings from deformation.

The aim of this study is to evaluate the influence of vertical planting using a *Parthenocissus quinquefolia (L.) Planch* on the surface measuring temperature of the building.

The study was carried out using a climbing plant (*Parthenocissus quinquefolia (L.*), which is one of the largest climbing plants growing in the territory of Lithuania. The stems of these plants grow up to 15–20 m in height. The plant is characterized not only by rapid growth, but also by the ability to attach to the surface, is undemanding to soil, moisture, resistant to winter conditions and suitable for vertical planting. For the growth of the plant, considering the need to ensure the durability of the facade of the building, a metal frame is formed. The empirical experiment was carried out on the south side of the building with wooden frame structures. The change in temperature was recorded on the surface of the vertical wall of the southern side of the building with and without landscaping. The surface temperature of the greened wall, at the radiation intensity at noon of the sun 399 W/m^2 and the ambient air temperature 21.5°C, changed from 17.2 to 30.9°C – the temperature during the day increased by 13.7°C. The temperature of the ungreened wall ranged from 17.8°C to 43.5°C – the change during the day was 25.7°C. The maximum difference between the planted and unplanted parts of the wall of the building is 12.6°C, at an outdoor air temperature of 21.5°C. This difference in the temperature of the same surface allows us to state that the planting of vertical surfaces with climbing plants forms a natural barrier that reduces the effect of direct sun on the surface of the building and lets effectively cool buildings in the mid-latitude zone.

From national policy to campus practice: circular economy-based waste management at the University of Life Sciences "King Mihai I" from Timișoara

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To advance the implementation of the United Nations 2030 Agenda for the Sustainable Development Goals (SDGs), global climate commitments, and the European Union's objectives set out in the Climate Action Plan (PAEC), and in line with the principles of the European Green Deal, the Romanian Government has adopted an action plan for the National Strategy on the Circular Economy. At the national level, Romania's transition towards a circular economy is further supported by strategic frameworks such as the Sustainable Development Strategy 2030 and the National Recovery and Resilience Plan. Concrete actions, particularly those focused on waste reduction, alleviate pressure on natural resources, stimulate investment in innovative technologies, and support job creation, forming the foundation of the National Strategy on the Circular Economy. Among the economic sectors with the greatest potential for circular economy implementation are construction, agriculture and forestry, food and beverage production, as well as the waste and water sectors. In this context, the aim of the present study is twofold: (i) to examine how waste management practices are implemented at the University of Life Sciences "King Mihai I" of Timișoara, and (ii) to demonstrate how responsible consumption and environmental education are promoted as good practices among students. Furthermore, the study examines the involvement of the academic community and highlights students' active role in promoting circular economy principles. Student engagement is achieved through curricular and extracurricular activities, practical training courses, workshops, and awareness-raising initiatives focused on waste reduction, recycling, and responsible consumption. Academic staff support these efforts by embedding waste management and sustainability topics into teaching and research, while non-academic staff ensure operational implementation, monitoring, and day-to-day maintenance of the system. These actions exemplify good practices in implementing EU and national strategies for resilient urban landscapes.

The impact of Fischer–Tropsch wax addition on the rheological properties of bitumens

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Bitumen is widely used in asphalt pavements; however, its performance is highly sensitive to temperature variations, leading to rutting at high temperatures and cracking at low temperatures. These limitations reduce pavement durability and increase maintenance costs. Although polymer-modified binders improve performance, they are often associated with higher cost and sustainability concerns [1]. Fischer–Tropsch wax (FTW), a synthetic hydrocarbon wax produced through gas-to-liquid synthesis, has emerged as a cost-effective alternative, particularly for Warm Mix Asphalt (WMA) applications [2].

FTW has a high melting point of approximately 101°C and, when added at contents of 2–4%, significantly reduces binder viscosity, enabling lower mixing and compaction temperatures while improving workability. In this study, FTW was incorporated at 2%, 4%, and 6% by weight into conventional 50/70 penetration-grade bitumen and polymer-modified PMB 45/80-55. Physical properties were evaluated using penetration, softening point, elastic recovery, and tensile strength tests, while workability was assessed through dynamic viscosity measurements. Rheological behavior was examined using a Dynamic Shear Rheometer (DSR) by determining the complex shear modulus ($|G^*|$) and phase angle (δ). Short-term aging was simulated using the Rolling Thin Film Oven Test (RTFOT).

The results indicated that FTW increased binder stiffness and softening point while significantly reducing viscosity, particularly at high temperatures, thereby enhancing workability for WMA production. DSR results confirmed improved rutting resistance and elastic behavior at FTW contents of 2–4%. After RTFOT aging, FTW-modified binders maintained favorable rheological stability. However, excessive FTW content (6%) caused over-stiffening, which may negatively affect fatigue resistance and increase susceptibility to low-temperature cracking [3].

Overall, FTW proved to be an effective modifier for improving the high-temperature performance and workability of bituminous binders. A dosage of 4% FTW provided the best balance between stiffness, durability, and flexibility, making it the recommended content for WMA applications.

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Hospitality 360º: An operational circular economy model for sustainable and profitable hotel management

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The hospitality industry struggles to implement holistic sustainability models that deliver verifiable business outcomes, often perceiving a trade-off with profitability. This research presents the Hospitality 360º model, an integrated operational framework validated through expert panels and case studies. Its aim is to bridge this gap by demonstrating how a holistic approach – connecting operations, human capital, and marketing – transforms circular economy principles into a core competitive advantage.

Implementation across four hotels yielded synergistic results:

- Operational/Environmental: 28% and 22% reductions in energy and water use; waste diversion increased from 25% to 76%.
- Economic/Market: 12% operational cost reduction with 2.8-year investment payback; generated a 6.5% RevPAR premium.
- Social: Employee turnover halved (35% to 18%); local procurement increased by 42%.

This study validates the Hospitality 360º model as an effective blueprint. Key conclusions: 1) Profitability and sustainability are synergistic, eliminating the perceived trade-off; 2) Holistic integration across operations, people, and marketing is essential for creating a self-reinforcing value cycle; 3) The model provides a replicable roadmap for practitioners. It establishes integrated circularity as the most viable strategy for building profitable, resilient, and regenerative hotel enterprises.

Assessing the taxonomic utility of DNA barcoding in differentiating the genus *Irvingia* (Hook. F.)

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DNA barcoding has become a reliable molecular tool for species identification and taxonomical classification, most especially in plant genera with morphological similarities that complicate the traditional taxonomic methods. The ability of DNA barcoding to distinguish species within genus *Irvingia*, a group of ecologically and economically important tropical trees is assessed in this study. The genetic traits of individual and combined barcode sequences (matK+rbcL) were analysed to determine their discriminatory power.

A total of 37 *Irvingia* DNA barcode sequences were retrieved, aligned and subjected to phylagenetic analysis using the Neighbor-Joining method to examine the genetic relationships within the genus *Irvingia*. The genetic diversity and identification efficiency of matK and rbcL markers were compared, with a focus on their ability to resolve taxonomic ambiguities within the genus. The study compared the genetic diversity and the efficiency of species identification of two chloroplast markers, matK and rbcL, analysing their resolution power, ability to address taxonomic ambiguities and variability. This assessment was crucial in the determination of their reliability as suitability markers for differentiating *Irvingia* species.

Results showed that matK exhibited the highest discriminatory power, due to its substantial number of variable (595) and parsimony-informative sites (397), while rbcL demonstrated lower variability (19) and limited taxonomic utility having 4 parsimony-informative sites. The concatenated (matK+rbcL) sequences provided enhanced species differentiation, having 464 variable sites and 325 parsimony-informative sites, supporting the incorporation of multiple barcoding loci for accurate classification. Phylogenetic analysis using the Neighbor-Joining method further illustrated how different *Irvingia* species are related to each other by clustering them based on their genetic similarities. Some species were closely related, indicating they have evolved from a common ancestor, while others were more genetically distinct, confirming they are separate species. The concatenated (matK+rbcL) loci displayed the highest rate of identification (45.15%) compared to rbcL (27.78) and matK (21.43) having lower values. This indicates that DNA barcoding is a useful technique for species identification and understanding how they are connected through evolution.

The study highlights the importance of molecular barcoding in refining taxonomic classification, enhancing biodiversity conservation and also facilitating the sustainable management of *Irvingia* species. Providing a more reliable and precise method for identification of species, DNA barcoding improves biodiversity conservation strategies and suggests sustainable management practices for *Irvingia* species, which are important for ecological stability and economic utility. The result suggests that incorporating multiple barcode markers enhances species resolution and reduces the risks of misidentification. To strengthen delineation of species and taxonomic clarity furtherly, research should be conducted to integrate a larger genetic database, employing high-throughput sequencing technologies, exploring more molecular markers to enhance the accuracy in the identification of species within the genus *Irvingia*.

Socio-technical transitions toward a circular economy in the water sector: Collective imaginaries and legitimacy of resource recovery

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Despite significant technological advances, many circular water initiatives remain trapped in pilot phases and struggle to achieve large-scale implementation. This suggests that barriers to adoption may also be social and institutional [1, 4]. Existing research on societal acceptance of circular water technologies has mainly focused on individual-level determinants. Yet, it provides a limited understanding of how acceptance emerges within broader socio-technical transition processes [2]. In addition, relatively little attention has been paid to the role of collective imaginaries [3] – shared visions of desirable futures – in shaping whether innovations such as resource recovery are perceived as legitimate and socially desirable.

This study addresses this gap by examining societal acceptance as a legitimacy-building process within socio-technical transitions toward circular water systems. The research combines a systematic review with the development of a conceptual framework that integrates insights from acceptance studies and socio-technical transition theory. The proposed framework will be validated through two ongoing projects in the Mediterranean region that develop resource recovery technologies, a context facing increasing water scarcity and growing policy interest in sustainable solutions. These cases will provide empirical insights into how stakeholder discourses and collective imaginaries shape the legitimacy of circular water innovations through discourse analysis, correlation analysis and Multilevel Perspective. The systematic review analyzes 70 peer-reviewed empirical studies investigating public and stakeholder perceptions of reclaimed water reuse and nutrient recovery technologies. The analysis identifies seven recurring themes shaping societal acceptance across different geographical and institutional contexts. Perceived health risk emerges as the most influential factor, particularly concerning pathogens, micropollutants, and long-term exposure. However, perceived risks frequently diverge from scientific safety assessments and are strongly mediated by levels of institutional trust. The review also reveals that these responses reflect deeper collective imaginaries shaping how wastewater-derived resources are socially interpreted.

Building on these findings, the study proposes a conceptual framework that situates societal acceptance within socio-technical transition dynamics, where legitimacy connects technological innovation niches with established water governance regimes and broader landscape pressures such as water scarcity and climate change. The study contributes to the literature by linking socio-technical transition theory with research on societal acceptance and by highlighting collective imaginaries as a key mechanism shaping the legitimacy of circular water innovations. Understanding these legitimacy dynamics is essential for designing governance and engagement strategies capable of supporting the transition from pilot projects to widely accepted circular water infrastructures.

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F. POLICY, STANDARDS & SOCIETAL PERSPECTIVES

National transposition of Directive (EU) 2018/844: Comparative energy evaluation of a public building in Poland and Spain

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The building sector represents a major share of final energy consumption and greenhouse gas emissions within the European Union. In response to climate neutrality objectives and the decarbonization strategy established under the European Green Deal, Directive (EU) 2018/844 amended the Energy Performance of Buildings Directive (EPBD), establishing a common framework for improving building energy performance and limiting non-renewable primary energy consumption. Its practical implementation depends on national transposition into domestic legislation.

The aim of this research is to analyse and compare the transposition of Directive (EU) 2018/844 into Polish and Spanish national regulations through the assessment of a real public building located in Choroszcz, Poland. The building, with a total constructed area of 1,729 m², is connected to a high-efficiency district heating network (96% efficiency) and includes a solar thermal installation for domestic hot water production.

The building energy performance was first evaluated according to Polish regulations, resulting in a non-renewable primary energy consumption of 40.78 kWh/m²·year (33.76 kWh/m²·year for heating and 7.05 kWh/m²·year for lighting), complying with national requirements. The same building was subsequently reassessed under the Spanish regulatory framework (Código Técnico de la Edificación – DB-HE), adapting climatic parameters, primary energy conversion factors, and renewable contribution requirements. The comparative results revealed variations of approximately 20% in calculated non-renewable primary energy consumption.

These differences are primarily attributable to distinct primary energy conversion factors and to the different regulatory structures adopted by each country. Poland's energy mix, historically more dependent on solid fuels and district heating systems, is reflected in conversion factors and regulatory priorities that differ from those of Spain, where policy frameworks have strongly promoted renewable energy integration and solar technologies.

The conclusion is that national energy policies significantly shape the way European directives are transposed into domestic legislation. The transposition of Directive (EU) 2018/844 is not merely a technical adaptation process but also an expression of national energy strategies and decarbonisation pathways, influenced by each country's energy structure, climate conditions and policy priorities. Coordination in methodological criteria would enhance comparability across Member States, respecting the diversity of national energy transitions within the European climate neutrality goals.

Urban carbon sequestration as a climate-neutrality strategy: Nature-based solutions in Timișoara, Romania

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In the context of rapid demographic growth, intensive urbanisation, and the increasing negative impacts of climate change, there is an urgent need for applied and efficient solutions that support sustainable and resilient metropolitan areas. Timișoara, located in the Western Romanian Plains within Timiș County (45.75372°N; 21.22571°E), is a regional centre experiencing continuous expansion and metropolitan transformation. The city is projected to face substantial increases in both the frequency and duration of compound heat–hazard (CHH) events, with values expected to nearly double by 2050 and increase further by 2100. Moreover, the growing debate between conventional grey infrastructure and blue–green infrastructure in urban landscapes has made the identification of hybrid solutions that integrate both systems a critical priority for Timișoara's sustainable urban development. Consequently, the implementation of the policies outlined in the 2023 Green City Action Plan for Timișoara, such as minimising the negative impacts of construction-related material supply chains, promoting the recycling of construction and demolition waste for use in the production or refinement of building materials, and encouraging the adoption of green roofs, becomes pivotal. The aim of this research is twofold: (i) to promote green roofs as Nature-Based Solutions (NBS) for urban carbon sequestration in support of climate-neutrality strategies, and (ii) to actively involve the academic community in practical activities aimed at identifying optimal landscape planning solutions for the campus library of the University of Life Sciences "King Mihai I" of Timișoara, serving as a pilot model for green roof implementation at the city level. In this respect, two green roof models were developed and evaluated: an extensive grass-based green roof and an intensive green roof, reflecting different structural, ecological, and management requirements. In both scenarios, carbon stock levels were estimated and compared.

Civic-led institutional innovation for recovery and resilience in wartime Ukraine: The ecofortress: restoring together model

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The full-scale war in Ukraine has generated large-scale environmental degradation and institutional disruption that severely complicate sustainable recovery of the built environment. Soil contamination, loss of green infrastructure and ecological fragmentation coincide with social displacement and weakened local governance capacities. These interconnected challenges require integrated recovery models that combine environmental reconstruction, civic participation and institutional adaptation. The aim of this study is to examine the EcoFortress: Restoring Together initiative as a civic-led model of institutional innovation supporting environmental recovery and social resilience in wartime Ukraine. To achieve this aim, the study addresses the following research questions:

1. How can participatory environmental projects strengthen local institutional capacity and governance resilience under wartime conditions?
2. To what extent can civic-led ecological restoration initiatives enhance community engagement and contribute to long-term sustainability in post-war reconstruction?

Results. EcoFortress: Restoring Together is implemented through four functional components:

1. Ecological diagnostics and spatial mapping of damaged territories;
2. Community-based reforestation and soil remediation;
3. Environmental education programs for youth and internally displaced persons;
4. Participatory urban greening strategies developed in cooperation with local governments.

Based on field observations, interviews with project participants and coordinators, and analysis of project documentation, the study demonstrates that EcoFortress: Restoring Together enables new forms of cross-sectoral collaboration between civil society organizations, universities and municipalities. The initiative expands the governance role of educational institutions, integrates formal and informal institutional practices, and increases the involvement of displaced youth in environmental planning and decision-making processes. These mechanisms improve social cohesion, strengthen institutional trust and promote adaptive governance under crisis conditions.

Conclusions. The EcoFortress: Restoring Together case confirms that civic-led environmental initiatives can function as effective instruments of institutional recovery in wartime contexts. By integrating sustainability goals with participatory governance and youth inclusion, the project contributes simultaneously to ecological restoration and social resilience. The model offers a scalable framework for green recovery and institutional innovation in war-affected regions and supports the development of resilient, sustainable built environments during and after conflict.

Comparison of financial support programs for photovoltaic micro-installations in Poland and Romania

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Following the adoption by the European Union (EU) of the FITfor55 package and the implementation of the REPowerEU plan, Member States are required to take action to reduce greenhouse gas emissions. In the building sector, these actions include, among others, the renovation of the buildings and their equipment to reduce final energy consumption. However, one of the most desirable actions is the increased use of renewable energy sources, including photovoltaic systems (PV). PV systems play a crucial role in buildings, as they not only supply electricity for building equipment but also provide power to heating sources such as heat pumps, enhancing their positive environmental impact. To increase the adoption of PV installations, it is essential to provide financial support from government institutions, especially for owners of small buildings such as single-family houses.

The aim of this study is to compare two financial support programs for photovoltaic micro-installations in Poland and Romania: the Polish program "Mój Prąd" and the Romanian "Casa Verde Fotovoltaice", which is currently passing through a transition phase reflecting changes in the national support policies for residential PV systems. First, an assessment of the current photovoltaic market in both countries was conducted, with particular attention to micro-installations. Subsequently, the objectives and scopes of both funding programs were analyzed. The requirements imposed on beneficiaries were compared, followed by an examination of the forms of financial support, the funding amounts, and the types of equipment covered by the programs. To better evaluate the scale of financial support for photovoltaic micro-installations, an economic analysis was carried out, taking into account wage levels (minimum wage and median earnings) in both countries.

The analysis demonstrated the relevance of implementing financial support programs for photovoltaic micro-installations as one of the key measures for decarbonizing the building sector, while highlighting the challenges related to the policies' stability. Actions aimed at increasing the use of PV systems are particularly important in the context of rising fossil fuel prices and growing concerns about their availability.

The deployment of PV systems helps reduce primary energy consumption from non-renewable sources. At the same time, it provides partial or full energy self-sufficiency for buildings, which is a fundamental element of ensuring energy security and supports the transition toward more decentralized and flexible energy systems.

MCDM/MCDA methods and the smart city concept – a review of applications and the case study

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The smart city concept is one of the main trends in the development of modern cities, and encompasses six main pillars: smart economy, smart people, smart governance, smart mobility, smart environment, and smart living. The research conducted addresses both theoretical issues and various measurements of selected entities in light of smart city indicators. The primary aim of the article is to review the applications of MCDM/MCDA (Multi-Criteria Decision Making/Multi-Criteria Decision Analysis) methods to the broadly defined concept of a smart city. The secondary objectives include: identifying the most popular MCDM/MCDA methods used in the context of smart cities, identifying additional tools and technologies, recognizing the most common decision-making problems related to smart cities, and providing a general assessment of the usefulness of these methods. The literature review was conducted based on selected scientific publications indexed in two databases. The findings indicate that the most frequently applied multi-criteria decision-making methods in the smart city domain are TOPSIS (mainly for ranking purposes), as well as AHP and DEMATEL (for weighting and analyzing relationships between decision factors). In addition to classical approaches, their modified versions are increasingly used, such as FTOPSIS, IF-AHP, and IF-DEMATEL. Moreover, based on the literature review, the main research sectors related to multi-criteria decision-making support were identified. The first sector, "rankings" concerns the application of methods for evaluating and ranking cities in terms of the smart city concept and the associated sustainable development paradigm. Two subsequent, interrelated sectors focus on intelligent transport and energy-related issues. Another sector includes studies on shaping policies that foster smart city development, addressing, among others, contemporary barriers and challenges in this area. The final group consists of studies on waste management in smart cities and research on urban digitalization. The article also included the case study to facilitate the assessment of the usefulness of selected methods. The case study focused on smart mobility in Polish cities.

Energy poverty assessment: an aggregated index for measuring urban vulnerability

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Energy poverty is increasingly recognised as a multidimensional challenge affecting the resilience, health, and social equity of European cities. Despite the availability of consolidated national indicators, current monitoring frameworks often lack the spatial granularity required to support local decision-making and targeted interventions. This research develops an integrated approach that combines socio-economic vulnerability, building-related characteristics, climatic exposure and urban morphology to identify energy poverty risk at submunicipal scale, with a specific focus on the Italian context.

The study builds upon recent advances in composite indicators and the methodological frameworks proposed by the Energy Poverty Advisory Hub (EPAH), the Joint Research Centre (JRC), and national observatories such as OIPE. A comparative review of existing indicators (consensual, expenditure-based, direct/indirect, and composite) highlights their strengths and limitations, particularly regarding hidden energy poverty and the lack of territorial sensitivity. The original contribution of this work lies in the development of a situated methodological framework that integrates high-resolution territorial drivers with consolidated European indicators and introduces a context-adaptive weighting system capable of reflecting the differentiated relevance of vulnerability dimensions across urban environments.

Preliminary results concern the methodological validation of the framework. The hierarchical organisation of indicators ensures internal coherence across scales, while the integration of local microclimatic and building-stock variables demonstrates the added value of high-resolution data in capturing spatial disparities that remain invisible in national statistics. The territorial weighting system further enhances the capacity of the framework to reflect context specific vulnerabilities, overcoming the limitations of existing composite indicators that assume uniform relevance of all dimensions.

The findings confirm that a multidimensional and territorially grounded structure is essential for advancing energy poverty analysis in cities. The proposed approach enhances the capacity of local administrations to interpret vulnerability patterns with greater precision, supporting more informed and spatially targeted policy design.

Re-value European waterfronts: Rijeka's struggle for a beach

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The European waterfront is diverse. Extensive urban river fronts stretch from the beach filled south to the cliff rich north. As the majority of the urban population is settled alongside a waterfront, the European water system raises urgent climate related concerns. Within this context, the blue element is not only a space of exposure, but a climatic regulator whose ecological performance directly affects urban resilience and the pursuit of climate neutrality. The Horizon Europe funded project Re-value, focused on climate neutrality of European waterfront cities, challenges local water management schemes through collaborative urban planning. A holistic approach to the waterfront joins urban quality with climate neutrality by understanding water as a mediator of heat, flooding and energy transition processes that contributes to decarbonization as much as adaptation. The project develops methodologies based on nine geographically, culturally and economically diverse European cities. In this framework Rijeka serves as a primary case study for deep-sea port typologies along the Adriatic coast.

Rijeka's industrial past, working class identity and border-side position have produced a coastline fully inhabited by port activities. Following the decline of heavy industries, prime waterfront grounds remain occupied by industrial ruins, while the Rječina, a freshwater torrent, runs through a concrete reinforced basin bordered by major traffic corridors. Such spatial separation from both sea and river has diminished the capacity of the blue system to operate as urban climate infrastructure and has reinforced sealed surfaces and automobile dependency. A focal point of the project in Rijeka is mobility, as most of central urban surfaces are largely covered with parking spaces, making the pedestrian corridors subject to the needs of the automobile. Re-engaging the riverfront is therefore framed not only as spatial reclamation, but as climatic intervention that reduces carbon intensive mobility patterns. With that, broader discussion on demographic challenges and developmental priorities arise, namely, the problematic terrain of the city as well as its vast industrial ruins. The cultural, artistic and academic atmosphere in Rijeka is rich, but the administrative challenges, with most of its waterfront under the jurisdiction of the National Port Authority, paralyse municipal bodies. Tactical urbanism and Nature Based Solutions, supported by an active civil society, are positioned as low threshold climate devices that improve microclimatic conditions, strengthen flood resilience and contribute to long term carbon neutrality.

Structured through three innovation cycles, namely collective story building, data driven scenario building, and investment and partnership development, the Re-Value methodology addresses six systemic challenges including governance, spatial quality, circular value chains, digital co-creation, energy, mobility and nature based solutions. With such a wide range of topics, results of participatory processes emphasize the importance of an iterative and case to case approach to both urban planning on a micro and macro scale. The strategic use of multiple small scaled urban interventions with a distinctly experimental character adequately address the capacities of smaller scaled municipalities tasked with waterside maintenance.

Sustainable traffic flow regulation during road reconstruction: A multi-criteria analysis

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Balanced road transport plays a crucial role in ensuring the mobility of people and goods while supporting economic and social cohesion. However, increasing traffic volumes and evolving societal demands expose the limitations of existing infrastructure, particularly gravel roads, which contribute to reduced safety, lower driving comfort, and increased environmental impacts such as air pollution and noise.

This study aims to evaluate alternative traffic flow regulation solutions during road reconstruction and to identify the most effective option using a multi-criteria decision-making approach. The research is based on a case study of a specific road section and follows the Road Technical Regulation KTR 1.01:2008 "Motorways". Traffic flow modelling is applied to simulate existing conditions and assess the impact of proposed solutions on traffic safety, capacity, and environmental performance.

A multi-criteria analysis is conducted under different weighting scenarios to reflect varying priorities in transport planning. The results demonstrate that integrated traffic regulation measures significantly improve traffic flow conditions, reduce conflict points, and enhance overall system efficiency. Furthermore, the findings reveal that the ranking of alternatives is highly sensitive to the assigned weights, with traffic safety and capacity emerging as the most influential criteria.

The study highlights that the integration of transport flow modelling and multi-criteria evaluation provides a robust framework for sustainable decision-making in road infrastructure development. The proposed approach supports the selection of optimal solutions that improve traffic performance while minimizing negative environmental impacts.

Decision support systems for urban water scarcity: Gaps, barriers and pathways to integrate nature-based solutions – a systematic review

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Giving priority to transforming urban water systems into resilient multifunctional infrastructures (as opposed to conventional grey infrastructure) is essential to meet the climate risks and growing demands of urbanization. Nature-based Solutions (NbS) can improve water security, restore ecosystems and contribute to multiple social gains. NbS have not been systematically integrated in urban planning, mainly because existing Decision-Support Systems (DSS) have been developed for centralized grey infrastructural optimization and therefore cannot model the adaptive, decentralized and socio-ecological nature of NbS.

To assess the extent of NbS integration into DSS addressing urban water scarcity, this study performs a systematic review of 50 publications in peer-reviewed literature from 2015 to 2025. The analysis identifies critical barriers across technical, institutional, socio-economic, and geographical dimensions. Technically, the key barrier is the lack of dynamic modules and common parameters to assess NbS performance in DSS. Institutionally, governance fragmentation and regulatory lock-in favor grey infrastructure. Socio-economically, limited stakeholder involvement and equity indicators marginalize local perspectives and distributional equity. Geographically, research has tended to concentrate in the Global North with regions of severe water stress underrepresented. Concurrently, the review also highlights new research opportunities in hybrid AI-physics models, Internet of Things (IoT) monitoring, digital twins, and participatory scenario co-creation.

In conclusion, we recommend that DSS development for urban water resilience transition from inflexible, efficiency-oriented optimization tools to adaptive, participatory decision-support systems. In this approach, our conceptual Decision-Support Framework (DSF) integrates hydrological models, real-time observations to identify the water scarcity scenario and use multi-criteria analysis to explore, evaluate and rank the context-specific NbS portfolios identified. Ultimately, this research underscores that mainstreaming blue-green infrastructure requires both technological innovation in digital twin environments and parallel institutional reforms to foster long-term urban hydrological resilience.

Bridging the quantification gap: A comparative analysis of empirical vs. theoretical sustainability metrics in on-site construction processes

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The construction industry accounts for approximately 40% of global energy use. While regulatory frameworks like EMAS, Level(s), and Green Building Rating Systems (LEED, BREEAM) have standardized sustainability assessments, a significant "quantification gap" remains regarding the on-site construction phase (Module A5). Existing literature highlights that only 2% to 2.5% of studies employ quantitative methods to evaluate real-time on-site operations, such as actual fuel use by machinery or temporary energy consumption. The aim of this research is to establish a common analytical framework to compare theoretical assessment methodologies with empirical construction-phase data, identifying the specific metrics used to evaluate GHG emissions and primary energy demand.

The preliminary comparative analysis reveals that most current sustainability frameworks rely on design-phase estimates and theoretical models rather than site-specific, dynamic variables. The study identifies that the exclusion of key factors – such as machinery efficiency variability, logistics, and weather conditions – can lead to significant discrepancies between predicted and realized environmental performance. Specifically, the research disaggregates how EMAS and Level(s) indicators assign metrics to construction activities like earthworks and structural erection, highlighting a systematic lack of empirical kg CO_2-e data per activity.

The research concludes that there is a measurable error gap arising from the reliance on theoretical models during the construction phase. To ensure that global decarbonization targets, such as the EPBD 2030 goals, are met, sustainability assessment methodologies must integrate empirical on-site performance data. This study provides a structured basis for improving the quantitative rigor of environmental frameworks, fostering a more realistic understanding of the building lifecycle's true environmental footprint.

Cultural influence on the perceptions of the fall of a real estate empire

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The collapse of Evergrande challenges the notion of "too big to fail". While there is ample housing research, studies on public perception of sporadic incidents such as the fall of a large-scale developer are scarce. How the public perceives the real estate industry and investment is directly associated with the individual large-scale company and is shaped by cultural differences. To fill this research gap, this study analyses 7038 Chinese and 4727 English YouTube comments through a cultural lens. The semantic network analysis shows that Chinese comments emphasised the impact on society and the Chinese government. In contrast, the English comments emphasised financial loss and housing problems, such as "tofu-dreg" and "empty apart(ment)". The sentiment analysis reveals that Chinese comments were more polarised than English ones. Collective cultures suggest that people often follow the group's acts, which is heightened by the spirals of silence: individuals feel comfortable expressing their opinions only when they align with the group or prefer to keep silent. On the other hand, the English comments display individualistic culture and focus more on negative aspects, as seen in Poe and Perkins' framing study. The regression results show that videos with higher engagement metrics attract more views, consistent with the Spiral of Silence (SoS) Theory. This study extends traditional real estate literature by offering a public perception lens alongside financial indicators, uncovering how cultural framing affects public opinion during the fall of the real estate empire. It also studies how collective opinions about a giant company collapse intensify in social media, highlighting the importance of monitoring public opinion in rebuilding trust in similar events, and emphasises the significance of implementing policies that facilitate global communication to bridge cultural divides and improve public views during a crisis.

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